WILD OAT SYMPOSIUM: PROCEEDINGS

Volume 1

Editor: Allan E. Smith

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WILD OAT SYMPOSIUM

PROCEEDINGS

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FOREWORD

This symposium, as previous symposia on wild oats held in 1973 and 1978, seeks to bring together current information on the biology and control of a persistent and very successful weed species. Comparison of these proceedings with those of the previous two symposia will reveal that in ten years, significant progress has been made in development of herbicides and in their general use for control, in understanding mechanisms controlling dormancy and in increasing awareness in the agricultural community of the importance of a major pest species in crop production. The formation of an action committee in 1973 served to focus attention on wild oats as a pest species. The campaign organized by the committee to synthesize the existing information, disseminate the information to the farmers and agri-business, and to encourage new research, has been an unqualified success. While wild oats have not been eliminated as a problem in crop production, the activities of the Wild Oat Action Committee have resulted in farmers of Western Canada having a greater knowledge of and ability to implement control measures. It is felt that the Wild Oat Action Committee has met its objectives and will terminate its activities with the conclusion of this symposium.

The organizing committee for the symposium join me in expressing gratitude to all the contributors for sharing their expertise; the sponsors, Agriculture Canada, the Wild Oat Action Committee, B.A.S.F. Canada Inc., Ciba-Geigy Canada Inc., Cynamid Canada Inc., Elanco Products, Hoechst Canada Inc., Monsanto Canada Inc. and Velsicol Inc.; Dr. M. Evelyn Jonescu, Director, Canadian Plains Research Center, University of Regina, for kindly agreeing to publish the proceedings; and Gillian Wadsworth Minifie, Coordinator of Publications for the Canadian Plains Research Center, for contributing her exceptional editorial skills.

The suggestions for program topics and overall organization of the symposium were handled by C.J. Bubar, A.I. Hsiao, J.H. Hunter, K. Mortenson and A.E. Smith. Special thanks are due A.E. Smith and A.I. Hsiao for drafting guidelines, soliciting and editing manuscripts and C.J. Bubar for arranging facilities.

J. Dueck
Chairman
Organizing Committee

APPENDIX

Common and chemical names of herbicides mentioned in the text (according to the Canadian Standards Association)

Asulam	methyl 4-aminobenzenesulphonylcarbamate
Atrazine	2-chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine
Barban	4-chlorobut-2-ynyl 3-chlorophenylcarbamate
Benzoylprop-ethyl	ethyl(±)2-(*N*-benzoyl-3,4-dichloroanilino)-propionate
Bromoxynil	3,5-dibromo-4-hydroxybenzonitrile
CDAA	*N*,*N*-diallyl-2-chloroacetamide
CDEC	2-chloroallyl diethyldithiocarbamate
Chlorpropham	isopropyl 3-chlorophenylcarbamate
Chlorsulfuron	2-chloro-N-[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)aminocarbonyl]benzenesulfonamide
Dalapon	2,2-dichloropropionic acid
Diallate	*S*-(2,3-dichloroallyl) diisopropylthiocarbamate
Dicamba	3,6-dichloro-2-methoxybenzoic acid
Dichlorprop	(±)-2-(2,4-dichlorophenoxy)propionic acid
Diclofop-methyl	methyl (±)-2-[4-(2,4-dichlorophenoxy)phenoxy]-propionate
Difenzoquat	1,2-dimethyl-3,5-diphenylpyrazolium methyl sulphate
Dinitramine	*N'*,*N'*-diethyl-2,6-dinitro-4-trifluoromethyl-*m*-phenylenediamine
Dinoseb	2-*sec*-butyl-4,6-dinitrophenol
EPTC	*S*-ethyl dipropylthiocarbamate
Flamprop-methyl	methyl *N*-benzoyl-*N*-(3-chloro-4-fluorophenyl)-2-aminopropionate
Ioxynil	4-hydroxy-3,5-diiodobenzonitrile
Linuron	3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea
MCPA	4-chloro-2-methylphenoxyacetic acid

Mecoprop	(±)-2-(4-chloro-2-methylphenoxy)propionic acid
Metribuzin	4-amino-6-*tert*-butyl-4,5-dihydro-3-methylthio-1,2,4-triazin-5-one
MH	maleic hydrazide
MSMA	monosodium methanearsonate
Paraquat	1,1'-dimethyl-4,4'-dipyridilium di-ion
Picloram	4-amino-3,5,6-trichloropicolinic acid
Propanil	3',4'-dichloropropionanilide
Propham	isopropyl phenylcarbamate
Sethoxydim	2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexene-1-one
TCA	trichloroacetic acid
2,4-D	2,4-dichlorophenoxyacetic acid
2,4-DB	4-(2,4-dichlorophenoxy)butyric acid
2,4,5-T	2,4,5-trichlorophenoxyacetic acid
Triallate	*S*-2,3,3-trichloroallyl diisopropylthiocarbamate
Trifluralin	2,6-dinitro-*N,N*-dipropyl-4-trifluoromethylaniline

WILD OAT SYMPOSIUM

PROCEEDINGS

WHAT HAS THE WILD OAT ACTION COMMITTEE DONE IN 10 YEARS?

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It was with some trepidation that I accepted the invitation to review what the Wild Oat Action Committee has done in the ten years, since its inception in 1973. For the first four years when I was totally involved as its first chairman the task would have been much easier. However, having accepted, I have given the subject much thought and decided that, even though I retired from Agriculture Canada in 1978 and have been working for the Canadian Seed Growers' Association since that time, I would try to give my impressions of the work that has been accomplished in the last ten years.

In order to properly set the stage for my remarks I would like to quote from the second paragraph of Dr. Jim Hay's remarks to the '78 seminar:

> In 1972 there was a ground swell of interest in wild oats. It took place independently in the U.K., Canada and the U.S. Lem Shuttleworth, of the Canada Grains Commission was one person whose voice was raised in Canada at the time. Speaking as a farmer, he complained of his lack of ability to get good wild oat control on his own farm and professionally he told us of the problems created by wild oats in the grain handling system and in marketing of the grain. In 1969-70, 487,000 tons of dockage were handled; or stated another way, 33 carloads of dockage were moved to the terminals every day. It cost $2,000,000 to move this dockage and another $8,000,000 to clean it out. He also stated that sales of barley were being lost because our top grades contained more wild oats than that of our competitors.

Lem Shuttleworth's remarks, in my opinion, initiated the thought that some action should be taken. The United Grain Growers took the initiative and at their 1972 meeting recognized the problems and requested that their company donate money and effort towards research on wild oats. In order to get something of a positive nature started, they suggested that they, with the cooperation of Agriculture Canada, would sponsor a seminar on wild oats. The rest is history as most of you are aware, because out of this meeting a Wild Oat Action Committee (WOAC) was formed. I think I would be remiss if I did not mention the names of the original members of the WOAC. There have been many changes over the years, but the members of the first committee deserve special mention because they set the stage for the successful campaign which engendered an awareness of how serious the wild oat problem had become.

While Forrest Hetland was not on the Committee, he was the one-man nominating committee who selected the group that formed the first WOAC. I know that all of you are aware of who Forrest is, but he deserves special mention. Forrest was a seed grower and farmer from Naicam, Saskatchewan, on whose land we at the Regina Station conducted wild oat chemical trials with Monsanto's Avadex. Forrest then moved to the Canadian Grain Commission and finally to the Canadian Wheat Board. One can say that Forrest has a wide knowledge of wild oat problems from the farmers' point of view and also from that of the Canadian Grain Commission and the Canadian Wheat Board.

Three farmers were selected to serve on the committee and I must say they provided an input that was extremely useful. They were Bob Adrian from Portage la Prairie, Manitoba, Sid Phillips from Tisdale, Saskatchewan, and Peter Bakker from Stoney Plain, Alberta. The prairie provincial governments provided three outstanding specialists in Orland Ratvold from Alberta, Vic Beck from Saskatchewan, and Jack Forbes from Manitoba. The Research Group was composed of Dr. Jim Hay from Regina Research Staion, the late Henry Friesen from the Lacombe Research Station, and Dr. Ross Ashford from the University of Saskatchewan. All of these men were well known for their dedication to wild oat research. The chemical companies were well represented by W.G. Pritchard of Monsanto, Peter Hayward, then with Gulf Oil Canada, and Jon Oliver from Elanco.

The grain companies' representatives were Dave Gilmore, then of National Grain, C.M. Ryan of the Saskatchewan Wheat Pool, and Lorne Hehn of the United Grain Growers who, without doubt, was a tower of strength to the Committee. The Canadian Wheat Board's representative was J.S. (Cam) Brown whose wide experience and sales ability made him a most valuable member. Last and least, I represented the Federal Government for two reasons - I had been involved in wild oat reasearch at Lacombe and Regina, and secondly, it was thought I might be able to con the government out of more funds for the WOAC than some other person. I knew that the Hon. Eugene Whelan and the Hon. Otto Lang supported the program 100 percent. This definitely helped, and I must say that the Information Division of Agriculture Canada and the Research Branch did provide essential support to the Committee.

The Committee was important, in my opinion, in that it was the first step in attempting to bring a primary focus on to one weed which most people considered the worst menace to increased production in western Canada.

The first objective of the committee was to create an awareness of the seriousness of the problem. This is not to say that nothing had been done before the WOAC's advent. The problem had been recognized and a lot of research on controlling wild oats was done. However, it was evident that we were not getting ahead of the problem; in fact, according to the statistics from the Canadian Grain Commission, the amount of wild oats being transported through the grain system was costing the farmers a lot of money, not only in reduced yields but in dockage, transportation and cleaning costs. The WOAC brought these facts to the attention of farmers, research workers, grain companies, chemical companies, and provincial governments.

Under the aegis of the WOAC each provincial government formed its own Wild Oat Action Committee. I can't say enough about the work of these committees. They organized meetings and seminars, schools, and performed their role of extension above and beyond the call of duty. The chemical companies, realizing that wild oats was not only a Canadian problem but a worldwide one, were spending millions of dollars looking for a selective wild oat herbicide. The first successful herbicides, triallate and barban, had arrived on the scene in 1959-61 and were recommended by the Western Weed Committee. There were many problems associated with these chemicals, such as stage of crop to spray, spraying techniques, and time of application.

In 1967 and 1972 only 650,000 and 900,000 hectares were sprayed. By 1972, three more chemicals were added, then in 1973 to 1975, six or seven more herbicides were on the market. This certainly had an impact as the hectarage sprayed rose rapidly from two million in 1973 to 6,600,000 million in 1977. While 24 million hectares are seeded to the six major crops in western Canada, it is safe to assume that, by now, about one-third of the land is sprayed with a wild oat chemical. It is also safe to assume that the fields sprayed were ones with heavy infestations of wild oats. The dockage figures supplied by the Canadian Grain Commission (Tables 1 and 2) show that there has been no appreciable reduction from 1971 to 72 or from 1980 to 81. These figures are for total dockage. In the early years both Dr. Candlish and Barry Hall estimated that wild oats comprised about 25% of total dockage. No figures or estimates are available for the past five years. However, it would appear to me that there must have been a reduction in the percentage of wild oats in dockage at least by 3 or 4%. While there may have been farmers who, for one reason or another, did not get as good results as they would have liked, many of them did get at least reasonable results. Otherwise the land sprayed would not be as high as 7.5 million hectares. Thus it seems to me that the wild oat chemicals have done at least an acceptable job. Farmers are not stupid and if they are not getting acceptable results they will not use the product. So I must say that even though it is a slow process we have been making progress. Essentially, this has been through the efforts of all those connected with WOAC Committees. I am sure that no one thought it was going to be easy.

Table 1 Percent dockage on car receipts of canadian grain at terminal elevators

Thunder Bay

Grain	1980 -81	1979 -80	1978 -79	1977 -78	1976 -77	1975 -76	1974 -75	1973 -74	1972 -73	1971 -72	Overall Percentage
Wheat	3.1	4.19	2.26	2.36	2.39	2.30		2.50	2.61	2.74	2.51
Oats	1.95	1.51	1.38	1.27	1.10	1.39		1.23	1.27	1.25	1.32
Barley	2.04	1.37	1.27	1.24	1.04	1.16		1.19	1.18	1.23	1.28
Rye	2.91	2.36	2.50	2.80	2.29	2.31		2.46	2.43	2.57	2.54
Flaxseed	9.87	8.51	8.83	9.40	10.40	10.70		9.49	8.85	10.89	9.63
Rapeseed	11.56	9.36	8.71	9.09	10.08	11.6		9.45	9.08	10.68	9.73
TOTAL (Total Net Dockage/ Total Gross Receipts	3.14	2.37	2.33	2.24	2.25	2.23		2.42	2.64	2.66	2.49

Table 2 Percent dockage on car receipts of canadian grain at terminal elevators

Pacific Coast

Grain	1980 -81	1979 -80	1978 -79	1977 -78	1976 -77	1975 -76	1974 -75	1973 -74	1972 -73	1971 -72	Overall Percentage
Wheat	2.81	4.71	2.24	2.36	2.74	2.53		2.75	3.09	3.09	2.71
Oats	10.68	-	-	.99	.96	2.11		.27	-	-	1.02
Barley	1.59	1.33	1.28	1.37	1.19	1.29		1.23	1.20	1.31	1.34
Rye	3.85	2.48	2.47	2.65	2.63	2.67		2.85	3.18	3.43	2.29
Flaxseed	9.10	8.63	8.19	8.62	9.54	10.06		9.42	9.29	10.75	9.41
Rapeseed	11.55	10.98	7.88	8.09	10.31	8.70		9.81	8.91	11.98	9.78
TOTAL (Total Net Dockage/ Total Net Receipts)	3.57	3.45	2.89	2.85	3.26	2.88		3.41	3.46	3.64	3.28

The Research Commmittee of the WOAC certainly has done a remarkable job. As previously stated, research on wild oats prior to the advent of the WOAC had been done. However, I think it has to be said that a lot more research was given top priority through the efforts of people like Dr. Jim Naylor and Dr. Jim Banting, who wanted to understand the reasons for the persistence of wild oats. You will hear more of this later. Surveys were conducted as to the extent of wild oat infestations on the prairies as far back as 1932 by J. Manson and in later years by J. Alex and G. Thomas. I look forward to Dr. Thomas's latest paper which should show if there has been any difference in the degree of infestation in the last ten years.

It is an almost insurmountable job to catalogue all the various research activities that have been undertaken. One can go from the results of cultural control which prior to the advent of chemicals was the major method, to mode of action of wild oat herbicides, incorporation techniques of herbicides, biological control, persistence of the chemicals, and many many others. All of these research studies have played a role toward a better understanding of the problems affecting the control procedures that have evolved. This symposium should bring you up-to-date on the detailed research work that has taken place in the last ten years and hopefully point the way to actions that must take place if we are to be able to provide adequate control of this most persistent weed. If Canada is to increase its production of cereal grain in line with the Agri-Food Strategy, we must find the answers to those things which mitigate against increased production.

I have been impressed with the work of the Information Sub-Committee. They have played an extremely important role in bringing the research results to the farmer. A lot of credit is due to the artistic work of Al McAllister of Agriculture Canada's Information Division in coming up with a logo that depicted wild oats as the Great Grain Robber. This was used on our letterhead, press releases, in film clips for television, and various meetings. To my way of thinking, these things captured the imagination of everyone and were responsible, in no small part, for getting the WOAC off to a good start. Coming back to the press releases for a minute: The Information Sub-Committee, with the help of Gayle Honey, the WOAC's writer and secretary, did a tremendous job of eliciting topical press releases from the researchers and other information offices. I hope that sometime a compendium of these releases can be compiled.

To sum up briefly on the topic assigned to me: What has the WOAC done in the last ten years?

1. They have certainly created an awareness of the problem of wild oats which was our first objective.

2. The WOAC stimulated more research activity on wild oats which has given us more answers as to the whys and wherefores of this persistent weed.

3. It has helped to stimulate the chemical companies into trying to find the chemicals that would do an adequate job in the control of wild oats.

4. The WOAC information series of press releases, workshops, and meeting have provided information on research results to farmers that have been of inestimable benefit.

5. Because of the increase in land sprayed to control wild oats infestations I have to believe that, while it may be small in total, we must have reduced the incidence to some extent.

6. The provincial committees' role cannot be underestimated. They brought the facts to their farmers in a way that showed, and will continue to show, positive results.

I fully realize that in various localities in each province there are other weeds which may be worse than wild oats. However, it seems to me that in the total prairie picture affecting crop yields, wild oats is still the number one menace. Progress has been made and with the dedicated people in all facets of the industry it is hoped that more progress will be forthcoming.

HISTORY OF DEVELOPMENT OF WILD OAT HERBICIDES

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The introduction of organic compounds as herbicides for the selective control of wild oats is a recent development. The testing of inorganic compounds for the control of weeds occurred over a longer period of time. In the 1950s, potential wild oat herbicides such as MH, propham, TCA and CDAA were tested with promising results. In 1960, diallate and barban were recommended for the selective control of wild oats in cereal grains or flax, and a major breakthrough was accomplished in removing a grass weed from a grass crop.

The introduction of dinoseb, a dinitro compound, in the early 1940s, and 2,4-D shortly after, marked the beginning of the modern-day use of selective herbicides. In 1947, nearly a million acres of cropland were sprayed with 2,4-D. However, the selective control of many broad-leaved weeds by 2,4-D assisted the growth of wild oats as much as it did the crop and thus the wild oat problem was increased. With the discovery of propham, chlorpropham and TCA, the selective control of grass weeds in broad-leaved crops appeared feasible, but selectivity within grass species still posed a problem.

Prior to these developments, weed control by cultural methods was worked on extensively. In the early 1930s, a Weed Investigation Nursery was set up by the Field Husbandry and Ecology Department at the University of Saskatchewan, Saskatoon. As a result of this and other work, information on the life history of certain weeds was obtained, and farmers were encouraged to practice (a) preseeding tillage in the spring to stimulate weed growth, (b) delayed seeding to control wild oats, (c) fall tillage and the use of barley the following season to help control wild oats, (d) the use of green feed crops to prevent reinfestation by seeds, (e) the use of fall-seeded crops such as fall rye to check weed growth, and (f) the use of forage crops, such as grasses and legumes, in a crop rotation or seeded separately and left down for a number of years to try and reduce the weed populations.

Some of these methods were useful - but results were inconsistent and costly in terms of reduced crop yields. The spread by seed of annual weeds such as wild mustard, wild oats and wild buckwheat was enhanced also by the introduction of the combine harvester. The invasion and spread of some of our perennial weeds, such as Canada thistle, was more spasmodic in that the infestations increased and decreased with periods of wet and dry weather.

The method for controlling perennial weeds, like Canada thistle and quackgrass, promoted at this time was known as the black summerfallow method. The infestations were generally confined to small areas, and the object of the method was to restrict the top growth in these patches at regular enough intervals so that the root reserves were depleted and the plants eventually died. The method was more effective in dry than in wet seasons. However, the bare patches that resulted from the extra cultivation were often a source of soil erosion by wind and the erosion from a few patches frequently spread to include a wide area -- often a whole field.

During the dry periods of the 1930s, the farmers in some areas had to combat soil erosion by wind more urgently than weeds and, as they learned to control the erosion by maintaining a trash or straw cover on their fields, they introduced practices that are still used in many of the drier areas of western Canada. The plow is seldom used today and deep tillage, below 10 cm, is not recommended. The heavy-duty cultivator and the rod weeder are used to maintain a straw cover on the soil surface while excess amounts of straw are worked into the soil with a discer. However, the use of a discer-seeder in some areas is often confined to seeding operations in the spring. In some areas, a two-year rotation of alternate crop and summerfallow was introduced to help keep weeds such as wild oats in check. With this method complete control of weeds could be obtained every second year, and the additional soil moisture conserved reduced the chances of a crop failure.

The full explanation for the yield increases following summerfallow is not known. Benefits are believed to be due to (a) the additional soil moisture conserved during the non-crop year, (b) increase in available nitrates, (c) less competition from weeds, (d) some control of plant diseases, and (e) improved seed-bed conditions.

In 1947, the National Weed Committee (Western Section) was set up to appraise and coordinate weed control research and the First Western Canada Weed Control Conference was held in Regina. The weed control conferences met annually until 1953, after which they met every second year and the National Weed Committee (Western Section) meetings were held in alternate years. Eventually the conferences were discontinued and the NWC meetings were held every year. In 1969, the name of the committee was changed to the Canada Weed Committee (Western Section) and it is now called the Expert Committee on Weeds (Western Section). Members of the committee consist of representatives from the Federal and Provincial Departments of Agriculture, Agricultural Colleges of four western universities, and two members of the Canadian Agricultural Chemicals Association representing the companies that provide potential herbicides.

Following the introduction of 2,4-D, the number one weed problem in western Canada switched from wild mustard to wild oats, and H. W. Leggett was chosen as Project Leader for Research in wild oat control for the NWC (WS). As a result, an intensive research program was started to evaluate or determine cultural and chemical methods to control wild oats. In 1955, a series of cultural experiments was started at several Research Stations which resulted in the Canada Department of Agriculture publication 1044 entitled, Cultural Control of Wild Oats, published in 1959. E. S. Molberg, commenting on this in a seminar given on January 20, 1974, said "Cultural methods, such as after-harvest tillage, delayed seeding, crop competition, etc., while they worked fairly well sometimes, were not consistently reliable."

In 1952, George Knowles, Dominion Weed Specialist, reported sterilizing wild oat seeds by spraying the plants in the milk stage with MH (maleic hydrazide). He published his results in 1953 and the following year tests were begun in western Canada. Results from the latter indicated that a high percentage of the wild oat seeds were sterilized by the use of MH. However, because of the late stage of application and sterilization of the seed of cereal grains, the treatment was never recommended.

In the 1950s, wild oat control was obtained in crops such as peas with TCA, dalapon, propham and chlorpropham, but selectivity was not obtained in cereal crops or flax. In 1957 and 1958, a large number of experimental chemicals were tested, including 1,2,4,5-tetrachlorobenzene, propham, chlorpropham, CDAA, CDEC and EPTC. All of these gave some wild oat control.

Diallate and barban were first tested in western Canada in 1958 with promising results. In 1960, they were recommended for the control of wild oats on a full or a trial basis in flax, barley or wheat. With diallate, a soil-incorporated herbicide, flax was highly tolerant, barley moderately so, and wheat the least tolerant. With barban, a postemergent treatment, wheat and barley were more tolerant than flax. For best results, barban had to be applied when the majority of the wild oats were in the two-leaf stage of growth. Barban is now registered for use in wheat, barley, flax, mustard, canola, sunflower, peas, lentils and fababeans.

Triallate, an analogue of diallate, was developed shortly after and was recommended for commercial use in 1963. Wheat and barley were more tolerant to triallate than to diallate and use of diallate was eventually discontinued. With both herbicides the safety margin of the crop was increased if the wheat was sown 1.3 cm or more below the treated layer of soil. Triallate can now be used in spring or durum wheat, barley, canola, flax, mustard and peas.

In 1965, trifluralin, another soil-incorporated herbicide, was recommended for use as a pre-planting treatment for the control of wild oats in canola, sunflowers and mustard. The recommendation has since been extended to include peas, fababeans and flax. Trifluralin also controls green foxtail, barnyard grass, wild buckwheat, redroot pigweed, lamb's quarters, Russian thistle, chickweed, purslane, knotweed and Persian darnel. Immediate and thorough incorporation is required with trifluralin and a number of precautions are listed with regard to its use in flax. Loss of soil moisture and loss of trash cover from the extra tillage required for incorporation should be taken into account.

Asulam was recommended for the postemergent control of wild oats in flax in 1973. Application should be made when the wild oats are in the two to four-leaf stage and the crop is 2.5 to 15 cm tall. Asulam also suppresses the seedling growth of wild mustard, stinkweed, wild buckwheat, smartweed, lady's thumb, bluebur, green foxtail and barnyard grass. Produced in 1961, asulam was tested at Regina initially in 1963 with excellent results. However, a long delay occurred before the chemical was made available for further testing on wild oats. Precautions concerning the crop and the weather should be heeded when using asulam.

Benzoylprop-ethyl was recommended also in 1973 for the control of wild oats in wheat. Its use was extended subsequently to include wild oat control in rapeseed. Benzoylprop-ethyl was to applied to wheat at the three to four-leaf stage of the wild oats and to canola at the four to six-leaf stage of the wild oats. Benzoylprop-ethyl could not be mixed with herbicides for the control of broad-leaved weeds, and intervals of four to seven days had to be allowed before treating with these chemicals. The use of benzoylprop-ethyl was eventually discontinued and the chemical was replaced by flamprop-methyl.

Difenzoquat was introduced in 1974 to control wild oats in barley. Certain varieties of wheat were included later. Application should be made when the majority of the wild oats are in the three to five-leaf stage of growth. A range in rates of application is given for each crop. The amount suggested for use depends on the density of the wild oats and their stage of growth. Good spray coverage is important since the activity of the chemical depends largely on contact action. Difenzoquat can be mixed with certain chemicals to give wild oat and broad-leaved weed control. Precautions in its use as a mixture should be adhered to.

In 1975, EPTC was included as a soil-incorporated treatment for the control of wild oats in flax and sunflowers. Its use is currently confined to sunflowers. EPTC also controls barnyard grass, corn spurry, green and yellow foxtail, chickweed, lamb's quarters, prostrate pigweed, purslane, and redroot pigweed.

The chemical must be applied prior to seeding to a dry, trash-free soil and incorporation must be prompt, vigorous and deep. Excessive drying of the soil may thus prevent germination of the crop and lack of trash cover will leave the field susceptible to soil erosion by wind. Practices such as this cannot be considered as agronomically sound.

Dinitramine, another soil-incorporated herbicide, was also recommended in 1975 for wild oat control in canola and sunflowers. The instructions for its use on the label were difficult to interpret or follow and the tolerance of rapeseed to dinitramine was limited. For this and other reasons its use was discontinued.

In 1976, flamprop-methyl, a postemergent treatment, was recommended for the control of wild oats in spring wheat, with the exception of Selkirk. Flamprop-methyl is an analogue of benzoylprop-ethyl and affects the wild oat in a similar manner. However, flamprop-methyl has given superior results at lower rates and earlier stages of application than has benzoylprop-ethyl. Early treatment usually results in optimum yields, and vigorous crop competition improves the wild oat control. Flamprop-methyl should not be mixed with herbicides used for broad-leaved weed control. An interval of four or, in some cases, seven days should be allowed between the use of flamprop-methyl and the application of chemicals for broad-leaved weed control.

Diclofop-methyl, another postemergent herbicide, was also recommended in 1976 for wild oat control in spring and durum wheat, flax, canola and mustard. Since then, its use has been extended to include barley (except Klages, Betzes, Norbert), peas, lentils, fababeans, spring and fall rye, triticale, and sunflowers (except Corona). Diclofop-methyl also controls green and yellow foxtail, Persian darnel, barnyard grass and volunteer corn. Herbicides for broad-leaved weed control should not be applied before using diclofop-methyl. Diclofop-methyl can be mixed with bromoxynil but not with other herbicides, nor with insecticides, fungicides or fertilizers.

The testing of mixtures of wild oat herbicides alone or in combination with those used for broad-leaved weed control occurred with the introduction of new herbicides. A mixture of barban and benzoylprop-ethyl was suggested for use in controlling wild oats in wheat at a later stage than when barban was used alone. The mixture was applied at the three-leaf stage of the wild oats and the rate for each chemical was reduced by about one-half of that when they were used alone. However, the use of this mixture was discontinued when benzoylprop-ethyl was withdrawn from the market.

The other wild oat herbicides, triallate and trifluralin, are registered for use as a mixture to control wild oats and green foxtail in wheat or barley. After sowing the crop 5 to 7.5 cm deep the mixture is applied and incorporated by two harrowing at right angles to each other.

One of the first mixtures registered for use for the control of wild oats and broad-leaved weeds was asulam and bromoxynil (Buctril M) in flax. Treatment was not advised during hot humid weather, nor when the crop was under stress.

Difenzoquat can be used in a mixture with several chemicals including bromoxynil, the ester formation of MCPA and the low volatile ester formulation of 2,4-D. Difenzoquat should not be mixed with the amine formulation of 2,4-D or MCPA or with dicamba or mixtures containing these products.

The use of diclofop-methyl as a mixture with bromoxynil has been referred to above. The fact that diclofop-methyl should not be mixed with other herbicides, nor with any other products, should perhaps be noted again.

In 1983, registration was granted for another new herbicide, sethoxydim, for the control of annual grasses, including wild oats, green and yellow foxtail, barnyard grass, Persian darnel and volunteer cereals in rapeseed, flax, soybeans and sugar beets. A special oil concentrate must be added to all applications of the chemical.

Since most weeds can now be controlled by herbicides and essential elements can be supplied by the use of chemical fertilizers, the practice of keeping one-third to one-half of our cropland in summerfallow each year is being questioned. However, in areas where soil moisture is often in short supply dispensing with summerfallowing would seem hazardous. On the other hand, the land in crop might be increased with less risk whenever the moisture in the soil, as indicated by sampling, was known to be plentiful in early spring.

FIELD AND QUESTIONNAIRE SURVEYS OF CEREAL AND OILSEED CROPS IN WESTERN CANADA

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ABSTRACT

Recent surveys indicated that wild oats occurred in 75% of the fields in Manitoba, 70% in Saskatchewan, 60% in Alberta and 38% in the Peace River region of British Columbia. The mean density ranged from 14 to 18 plants per m^2 in occurrence fields when counts were made after the application of postemergence herbicides. About 5% of the fields had densities above 50 plants per m^2. Provincially, wild oats ranked as the second to eighth most abundant weed in the surveys. Producers ranked wild oats as the most troublesome weed in western Canada. Between 50 and 60% of Saskatchewan and Manitoba producers used one or more methods of cultural control, with fall tillage and delayed seeding being the most common methods. The use of herbicides for wild oat control has increased so that in 1981 in Manitoba 60% of the fields were treated. The largest proportion of the herbicide was applied before emergence of the crop. Detailed analyses of Saskatchewan data indicated that wild oats was more abundant on all soil textures. There was no indication that the wild oat problem was associated with one crop more than another.

RECENT WEED SURVEYS IN WESTERN CANADA

The purpose of this paper is to update the information I presented on the size of wild oat populations, the relative importance of the wild oats in relation to other weed problems, the use of cultural methods for control, the use of chemical control, and the source and method of cleaning seed at the 1978 Wild Oat Action Committee Seminar. Most of the data found in the tables in this presentation are from surveys which have been conducted in the Peace River Region of British Columbia, Saskatchewan, and Manitoba since the last symposium. Some older data are presented for comparative purposes. All the information has been extracted from the weed survey computer data base containing the results from the field counts of weeds, and from the questionnaires completed by the person who farmed the surveyed field. A portion of the data have previously been published in the annual or summary reports listed in the reference section.

All these surveys have used a similar procedure and a similar terminology, which is explained in the various reports. Weeds were counted during July and August in all surveys, with the exception of the Manitoba weed inspection survey and the Alberta survey. These surveys took place in June, the period prior to the application of postemergence herbicides. Data pertaining to these two survey projects appears only in Table 1.

The data presented in the following 12 tables are meant to serve as a point of reference to which the results of future weed surveys can be compared. Such a bench mark is necessary to provide the historical data which can be used to identify long term shifts in the abundance of wild oats. This assumes that surveys will continue to be conducted on a periodic and continuing basis.

REFERENCES

Thomas, A.G. 1976. Weed survey of cultivated land in Saskatchewan. Weed Survey Series Publ. 76-1. Agr. Can., Regina, SK.

Thomas, A.G. 1977. Weed survey of cultivated land in Saskatchewan. Weed Survey Series Publ. 77-1. Agr. Can., Regina, SK.

Thomas, A.G. 1978. Report on the 1977 weed survey and questionnaire in Saskatchewan, Weed Survey Series Publ. 78-1, Agr. Can., Regina, SK.

Thomas, A.G. 1978. Weed survey of cultivated land in Saskatchewan. Weed Survey Series Publ. 78-2. Agr. Can., Regina, SK.

Thomas, A.G. 1978. Weed survey of cultivated land in Manitoba. Weed Survey Series Publ. 78-3. Agr. Can., Regina, SK.

Thomas, A.G. 1979. Manitoba weed survey questionnaire data. Weed Survey Series Publ. 79-1. Agr. Can., Regina, SK.

Thomas, A.G. 1979. Weed survey of cultivated land in Saskatchewan. Weed Survey Series Publ. 79-2. Agr. Can., Regina, SK.

Thomas, A.G. 1979. Weed survey of cultivated land in Manitoba. Weed Survey Series Publ. 79-3. Agr. Can., Regina, SK.

Thomas, A.G. 1980. Manitoba weed survey questionnaire data. Weed Survey Series Publ. 80-3. Agr. Can., Regina, SK.

Thomas, A.G., and R.F. Wise. 1982. Weed survey of cultivated land in Manitoba. Weed Survey Series Publ. 82-1. Agr. Can., Regina, SK.

Thomas, A.G., and R.F. Wise. 1983. Peace River region of British Columbia weed survey (1978, 1979 and 1980). Weed Survey Series Publ. 83-4. Agr. Can., Regina, SK.

Wise, R.F., and A.G. Thomas. 1982. Manitoba weed survey questionnaire data. Weed Survey Series Publ. 82-2. Agr. Can., Regina, SK.

Table 1 Recent weed survey estimates of the size of wild oat populations in cereal and oilseed crops in Western Canada.

Location	Year	Number of fields	Percentage frequency		Field density (no./m^2)		Relative abundance	Rank in survey
			Field	Quadrat*	All	Occurrence		
British Columbia (Peace)	1978	361	40	19	4.1	10.3	15	7
	1979	390	32	13	3.4	10.7	10	8
	1980	377	43	19	9.4	21.9	17	7
	Combined	1128	38	17	5.6	14.8	14	8
Alberta (provincial)	1973	303	66	-	-	36.0	-	-
	1974	283	49	-	-	17.0	-	-
	1975	587	70	-	-	29.0	-	-
	1976	929	65	-	-	21.0	-	-
	1977	957	56	-	-	37.1	-	-
Saskatchewan (provincial)	1976	1022	72	30	13.3	18.4	40	2
	1977	1488	71	29	9.2	13.1	38	3
	1978	995	65	23	7.2	11.0	31	3
	1979	990	74	30	11.0	15.0	44	2
	Combined	4495	70	28	9.8	14.0	38	3
Manitoba (provincial)	1978	440	79	39	14.5	18.3	35	2
	1979	477	72	31	12.4	17.2	36	2
	1981	513	73	30	13.7	18.7	35	2
Manitoba (Weed Insp.)	1975	113	53	41	-	30.0	20	6
	1976	114	72	58	-	31.0	26	4
	1977	217	78	64	-	31.0	29	3
	1978	210	78	58	-	19.0	24	4
	Combined	654	73	57	-	27.0	25	4

* Frequency value is for all quadrats surveyed.

Table 2 The five weeds which producers in Manitoba, Saskatchewan and British Columbia (Peace River area) considered the most troublesome.

Saskatchewan (1978, 1979)		Manitoba (1978, 1979, 1981)		British Columbia (Peace 1978)	
Species	Aggregate score	Species	Aggregate score	Species	Aggregate score
Wild oats	3853	Wild oats	3137	Stinkweed	400
Green foxtail	1787	Green foxtail	2435	Wild oats	328
Wild buckwheat	1523	Canada thistle	1477	Redroot pigweed	82
Cow cockle	1160	Wild mustard	1271	Quack grass	81
Stinkweed	1098	Wild buckwheat	942	Narrow-leaved hawk's-beard	76

Table 3 The percentage use of three cultural methods for the control of wild oats in Saskatchewan, Manitoba and British Columbia.

Cultural control method	Saskatchewan		Manitoba			British Columbia (Peace)
	1978	1979	1978	1979	1981	1978
Fall tillage only (A)	14.4	15.6	16.5	26.5	23.1	15.2
Delayed seeding only (B)	12.6	15.6	14.7	8.9	12.7	2.7
Post-seeding tillage only (C)	9.1	4.8	4.8	3.3	3.7	0.4
Methods (A) and (B)	7.4	9.2	11.3	8.6	7.2	4.0
Methods (A) and (C)	5.6	4.1	3.9	2.5	2.5	3.3
Methods (B) and (C)	4.4	3.2	2.2	0.5	0.9	—
Methods (A), (B) and (C)	4.7	5.0	2.6	—	0.8	1.5
No methods used	41.9	35.3	44.2	40.7	46.8	70.0
No response	NA	7.2	NA	9.0	2.3	2.9

Table 4 Percentage of surveyed fields of each of four crops that received a wild oat herbicide in Saskatchewan, Manitoba and British Columbia.

Crop	Saskatchewan		Manitoba			British Columbia (Peace)
	1978	1979	1978	1979	1981	1978
Wheat	25.2	46.6	45.3	45.3	67.6	23.5
Barley	18.7	32.0	48.0	53.2	49.6	22.3
Rapeseed	78.1	87.6	92.8	82.1	79.0	29.8
Flax	50.0	61.9	23.1	47.7	52.5	NA
All four crops	29.8	50.6	51.6	54.2	60.5	25.4

Table 5 Percentage of surveyed fields which were treated with different types of wild oat herbicides in Saskatchewan, Manitoba and British Columbia.

Herbicide type	Saskatchewan		Manitoba			British Columbia (Peace)
	1978	1979	1978	1979	1981	1978
Single applications						
(a) Soil incorporated	80	66	58	49	28	83
(b) Post-emergence	16	24	15	22	23	10
Tank mixed with other chemicals						
(a) Soil incorporated	2	4	8	13	21	7
(b) Post-emergence	2	6	19	16	28	0

Table 6 Source of seed sown in Saskatchewan, Manitoba and British Columbia.

Source of seed	Percentage of surveyed area					
	Saskatchewan		Manitoba			British Columbia (Peace)
	1978	1979	1978	1979	1981	1978
Home grown	70	67	40	45	50	44
Elevator agent	5	4	18	6	5	25
Other farmer	8	8	4	10	10	10
Seed grower	16	18	33	38	32	19
No response	1	3	4	1	3	2

Table 7 Method used to clean the seed sown in Saskatchewan, Manitoba and British Columbia.

Seed cleaning method	Percentage of surveyed area					
	Saskatchewan		Manitoba			British Columbia (Peace)
	1978	1979	1978	1979	1981	1978
Country elevator	54	46	18	9	9	0
Stationary plant	22	30	52	72	70	69
Farm cleaned	10	10	15	9	11	17
Itinerant plant	7	8	8	4	5	4
Not cleaned or no response	6	6	6	6	5	10

Table 8 Estimates of the size of the residual wild oat populations in the five major Saskatchewan soil groups during the years from 1976 to 1979.

Soil group	Percent field frequency	Percent quadrat frequency		Field density (no./m^2)		Relative abundance	Rank in survey
		All	Occurrence	All	Occurrence		
Brown chernozemic	48	14	29	5.4	11.3	28	6
Dark brown chernozemic	74	28	38	11.0	14.8	38	2
Black chernozemic	82	35	43	11.1	13.6	40	2
Dark gray chernozemic	81	42	52	14.1	17.5	49	1
Gray luvisolic	81	32	40	8.4	10.4	36	1

Table 9 Estimates of the size of the residual wild oat populations on five soil textural groups during the 1976 to 1979 Saskatchewan weed survey.

Soil textural group	Percent field frequency	Percent quadrat frequency		Field density (no./m^2)		Relative abundance	Rank in survey
		All	Occurrence	All	Occurrence		
Fine (clays)	68	26	38	9.9	14.5	64	1
Moderately fine (clay loams)	69	26	38	9.0	13.0	44	1
Medium (loams)	73	30	40	10.7	14.7	37	3
Moderately coarse (sandy loams)	66	27	41	8.5	12.9	28	3
Coarse (sands)	56	24	42	7.3	13.0	30	3

Table 10 Estimates of the size of the residual wild oat populations in the six crops surveyed in Saskatchewan during the years 1976 to 1979.

Crop	Percent field frequency	Percent quadrat frequency		Field density (no./m^2)		Relative abundance	Rank in survey
		All	Occurrence	All	Occurrence		
Wheat	71	28	40	10.5	15.0	40	3
Barley	73	29	39	9.2	12.6	38	2
Oats	49	18	37	3.9	8.0	15	6
Rye	53	17	32	16.4	31.1	24	5
Rapeseed	77	32	41	7.6	10.0	39	1
Flax	76	28	37	6.5	8.6	40	2

Table 11 Percentage of survey area in which wild oats was found at four density classes in the Saskatchewan, Manitoba and British Columbia weed surveys.

Density class (plants/m^2)	Saskatchewan		Manitoba			British Columbia (Peace)
	1978	1979	1978*	1979	1981	1978
0	32	22	29	22	24	65
1 - 10	51	55	44	50	52	27
11 - 51	14	19	20	22	18	9
51+	3	4	7	6	5	0

*Percentage based on numbers rather than area.

Table 12 Percentage distribution of wild oats quadrat densities in Saskatchewan surveys during the years 1976 to 1979 (n = 24577) quadrats.*

Quadrat density (no./0.25 m^2)	Percentage
1	21.7
2	15.1
3	11.1
4	8.4
5	5.6
6	5.2
7	4.0
8	3.5
9	2.5
10	2.4
11-20	11.2
21-30	4.0
31-40	1.6
41-50	1.0
51-60	0.6
61-70	0.4
71-80	0.3
81-90	0.2
91+	1.2

* Wild oats occurred in 70% of the survey fields but 60% of the sample quadrats in these fields did not have wild oats. The above table is based on only the 40% of the quadrats with wild oats.

WILD OATS, COMPETITION AND CROP LOSSES

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ABSTRACT

This paper reviews the effect of wild oat (Avena fatua L. competition on yield and quality of cereal and oilseed crops and the factors which determine crop losses due to the weed. Generally, yield losses increase with increasing populations of wild oats. Crop quality is also reduced in some cases, especially with oilseed crops. Mathematical models based on "indices of competition" have been developed, which provide a quantitative means of predicting crop yield loss due to different wild oat densities. These can be used to determine the cost-effectiveness of wild oat control in different situations. The accuracy of the models may depend on a number of factors such as crop species, crop seeding rate, time of emergence of wild oats relative to the crop, and soil and climatic factors. Barley (Hordeum vulgare L.) is most competitive, followed by rapeseed (Brassica campestris L.), wheat (Triticum aestivum L.), and flax (Linum usitatissimum). Increasing the seeding rates of cereal crops generally reduces the wild oat competition. Yield losses in wheat and barley are most severe when wild oats emerge before the crop. However, reports on the time of onset of wild oat competition are variable. Drilling in phosphorus with barley seed provides the crop an advantage over the wild oats, whereas nitrogen appears to benefit both species regardless of method of application. The paper stresses the need for further research on the role of environmental factors in wild oat competition.

INTRODUCTION

Wild oats is one of the most economically harmful annual grassy weeds of cultivated land in many areas of the world, especially in North America, Europe and Australia. It has been estimated that nearly 30 million hectares of arable land in the northern plains of the Great Plains Regions of North America is infested with the species (Wood, 1953). Crop losses due to wild oats can be extensive. Projected annual losses of wheat and barley have been estimated at 2.2 and 6.4 million tonnes in Europe and North America, respectively (Nalewaja, 1977). Wild oats is found in all

Canadian provinces but causes the greatest economic losses in the three prairie provinces. It has been estimated that 17.3 million hectares of arable land in this region are infested with wild oats of which 13 million hectares has a moderate to heavy infestation (150 plants/m^2 or greater) (Alex, 1966). Annual crop losses and herbicide costs due to wild oats in western Canada alone have been estimated at $280 million (Dew, 1978a).

Although wild oats can cause economic losses through a number of added costs including dockage, increased transportation, storage and tillage costs etc., the greatest single cause of losses is reduced crop yields due to direct competition. Friesen (1973) estimated that of the $353 million annual loss caused by weeds in western Canada between 1968 and 1972, $209 million was due to direct competition.

This paper reviews the research to date on the effects of wild oat competition on yield and quality of cereal and oilseed crops, and the factors which determine the extent of crop losses due to the weed.

EFFECT OF WILD OAT COMPETITION ON CROP YIELD AND QUALITY

Wild oats is considered a strong competitor with most crops. It can adapt to a wide range of environmental conditions and possesses a very extensive crown root system (Pavlychenko and Harrington, 1934). Many reports indicate that wild oats can cause extensive yield reductions in a number of crops including barley, wheat, rapeseed and flax. Yield reductions due to wild oats (150-200 plants/m^2) have been estimated at 26% in barley and between 33 and 39% in wheat (Bell and Nalewaja, 1968a; Chancellor and Peters, 1974); 46% in rapeseed (Keys, 1975) and 86% in flax (Bell and Nalewaja, 1968b). Even at relatively light infestations (12 plants/m^2), wild oats significantly reduced yields of wheat and flax (Bowden and Friesen, 1967). Various studies suggest that the extent of the yield reductions due to wild oats is dependent on various factors including density, time of emergence of the weed and crop, and environmental factors.

Although information on the effects of wild oats on crop yield is considerable, comparatively little is available on the effect of the weed on crop quality. The protein content of wheat, barley and oats (Avena sativa L.) was increased when weeds (mainly wild oats) were removed (Friesen et al., 1960). Later studies, however, indicated that the protein content of wheat (Bowden and Friesen, 1967) and barley and wheat (Bell and Nalewaja, 1968a) were not affected by comparatively heavy wild oat infestations. The presence of other weeds in the earlier studies may have complicated the results. The effects of wild oat competition on quality of oilseed crops appear less uncertain. In flax, the oil content, iodine number of the oil (a measure of quality) and linolenic acid in the seed were reduced due to wild oat competition (Bell and Nalewaja, 1968b). These changes were evident even at low wild oat densities (12 plants/m^2) but did not occur until wild oats were in the heading stage, and flax in the boll stage (Bell and Nalewaja, 1968c). Removal of wild oats from flax and rapeseed either manually, or with a herbicide, increased the quality of the oil in both crops (Chow and Dorrell, 1979). It would appear that, at least in the case of oilseed crops, decreased yield due to wild oats should not be the only criterion used to estimate economic losses due to wild oat competition. There is a need for further research on the effect of wild oat competition on crop quality.

FACTORS AFFECTING COMPETITION

Competition between wild oats and crops is an extremely complex system and the extent of competition and subsequent effects on crop yields and quality will depend on a number of factors. These are depicted schematically in Fig. 1, and include species, density, duration of competition, and time of emergence of the crop and weed. Further influences will be exerted by the prevailing edaphic and climatic conditions, such as soil moisture, soil nutrient status, and sunlight during the growing season. The contribution of any one of these factors will vary depending on the influence of the other factors.

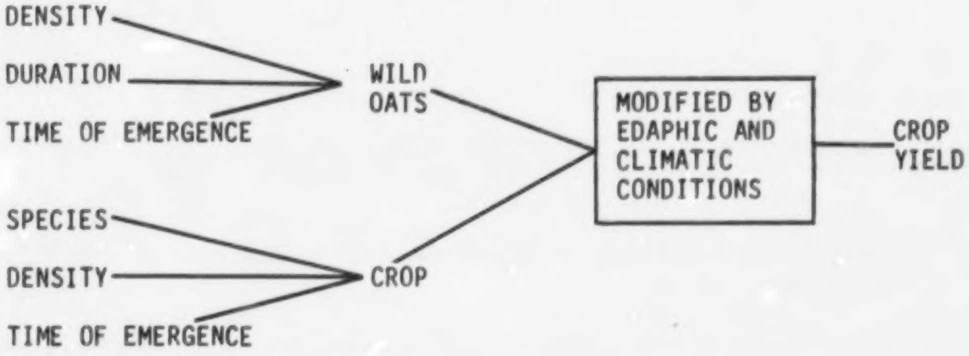

Fig. 1. Factors influencing weed-crop competition. (Modified from Bleasdale, 1960).

Effect of Wild Oat Density and Methodology for Predicting Crop Losses

A number of studies have indicated that, in general, as wild oat density increases, competition due to the weed becomes greater and crop yield losses increase. This has been shown in barley and wheat (Bell and Nalewaja, 1968a; Bowden and Friesen, 1967;

Chancellor and Peters, 1974), flax (Bell and Nalewaja, 1968b; Bowden and Friesen, 1967) and rapeseed (Keys, 1975). These and a number of other studies in various countries (dealt with in detail by Chancellor and Peters, 1976) generally found a good correlation between wild oat density and crop yield losses. In a recent study, however, barley yield was better correlated with dry weight of wild oats at harvest than with density (Wilson and Peters, 1982).

Most of the studies on effects of wild oats on crop yield did not provide a quantitative means of predicting losses due to different wild oat densities. Dew (1972) utilized the research data on wild oat competition generated by Bowden and Friesen (1967) and Bell and Nalewaja (1968a, 1968b) to develop a mathematical model to predict yield losses due to wild oats in barley, wheat and flax. A curvilinear relationship existed between crop yield and wild oat density (Fig. 2). The curves are expressed by the regression equation $y = a - b\sqrt{x}$ where y = yield, x = number of wild oat plants/m^2, a = predicted weed free yield and b = regression coefficient. The estimates for a and b obtained from the regression analyses were plotted to show their relationship (Fig. 3). An "index of competition" (b_1) was calculated from the equation $b_1 = b/a$ and can be used to estimate yield loss as follows:

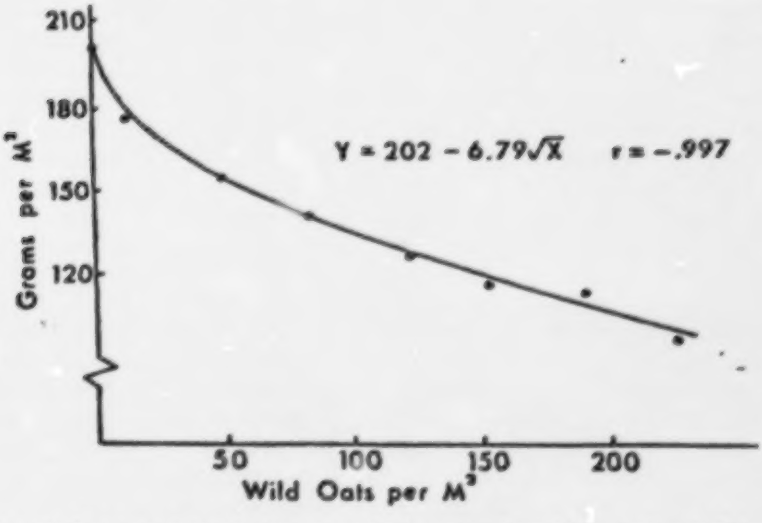

Fig. 2 Relationship between wild oat density and yield of wheat. (From Dew, 1972).

$$\text{yield loss} = ab_1\sqrt{x}$$

This can be expressed in percentage terms as follows:

$$\text{percent yield loss} = 100\, b_1\sqrt{x}$$

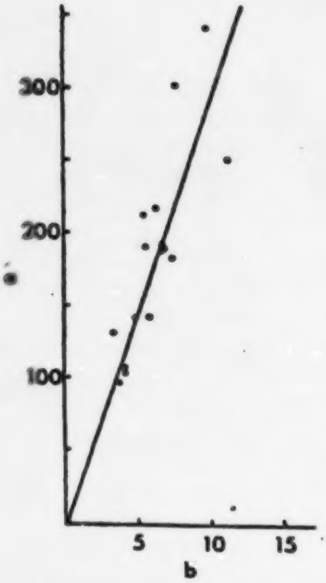

Fig. 3 Index of competition for wild oats in wheat where a = predicted weed free yield and b = regression coefficient. (From Dew, 1972)..

In a subsequent study, using data generated in Alberta and Saskatchewan, an "index of competition" for yield loss due to wild oats in rapeseed was determined (Dew and Keys, 1976). "Indices of competition" for wild oats in barley, wheat, rapeseed and flax are shown in Table 1.

Table 1 Indices of competition for wild oats in various crops

CROP	INDEX OF COMPETITION
Barley	0.0230
Rapeseed	0.0322
Wheat	0.0339
Flax	0.0601

(From Dew, 1972, and Dew and Keys, 1976).

Plotting the percentage loss derived from the model against the number of wild oat plants/m^2 provides a simple method of estimating crop yield loss due to various infestations of wild oats (Fig. 4). This information can be used to predict the economic threshold (the weed level at which the benefits of control equal the cost of the herbicide and its application) for controlling wild oats with herbicides. Whether or not control of wild oats is economical will depend on factors such as the potential weed free yield, the market price of the crop and the cost of the herbicide.

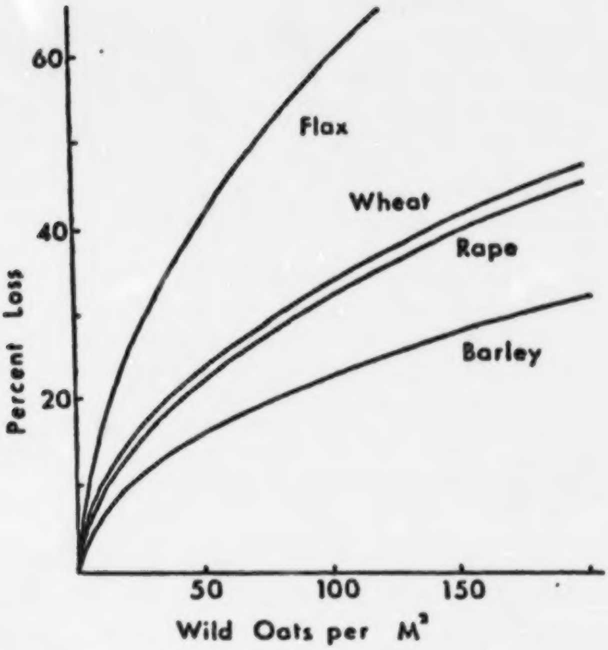

Fig. 4 Influence of wild oat density on yield loss. (From Dew, 1978a).

Field scale studies subsequently conducted in western Canada over three years confirmed the "indices of competition" for wild oats in barley and wheat (Hamman, 1979). Studies from Britain, (Scragg, 1980; Scragg and McKelvie, 1976), however, have indicated that the model is not applicable to all situations. Spring barley yield losses due to wild oats were found to be more severe than the mean effects predicted by Dew (1972) for North America. Such variations may result from the fact that the model (Dew, 1972) was derived based on the assumptions that 1) crop seeding rates were similar across all trials; 2) the wild oats and the crop emerged at the same time; and 3) the wild oats and crop had equal access to moisture, nutrients and light. Changes in any one of these assumptions may change the "index of competition" and, therefore, alter the extent of the predicted yield loss derived from the model.

Effect of Duration

For the purpose of this review, "duration" can be generally defined as the length of time wild oats are allowed to remain in the crop. The maximum time period weeds can be tolerated without affecting crop yield, or the point after which weed growth no longer affects crop yield, has been defined by Nieto et al., (1968) as the "critical period." The determination of the "critical period" is of great practical significance if appropriate weed control measures are to be instigated. Studies have been conducted in several countries, therefore, to determine the time of onset of wild oat competition and the intensity of competition with time. Generally, it has been found that the competitive effect of wild oats increases the longer they are allowed to remain in the crop. However, reports on the time of onset of wild oat competition vary. Studies in England (Chancellor and Peters, 1974) and in the United States (Lee et al., 1979), showed that wild oat competition began at the four-leaf stage of barley and wheat. In Australia, however, wild oat competition in wheat tended to occur throughout the life of the crop, but only at relatively high wild oat densities (110 plants/m^2) (McNamara, 1976). Reports from Canada are quite variable. In Manitoba, wild oat competition in wheat began prior to crop emergence at wild oat densities of 110 plants/m^2 or higher, while in flax, competition did not occur until the two to three-leaf stage of the wild oats (50 plants/m^2 or higher) or later, depending on the year (Bowden and Friesen, 1967). In Saskatchewan, wild oat competition in wheat began between the two to four-leaf stage of the wild oats (Sharma and Hunter, 1974). These results are at variance, however, with data generated in Alberta where significant yield reductions in barley, wheat, rapeseed and flax generally did not occur until after the five-leaf stage of wild oats (up to 270 plants/m^2) (Dew, 1975, 1976, 1977, 1978b). There was, however, some variation in the results from year to year. A recent study at Lacombe (O'Donovan and O'Sullivan, 1982a) indicated that significant yield reductions due to wild oats began before the four-leaf stage in wheat but not until after the five-leaf stage in barley (Table 2). There were no differences between manual removal of the weed and removal with diclofop-methyl.

Table 2 Influence of stage of removal of wild oats (150-170 plants/m^2) on yield of barley and wheat

TYPE OF REMOVAL	WILD OAT LEAF STAGE	YIELD (g/m^2) BARLEY	YIELD (g/m^2) WHEAT
Weed free check	-	488a[1]	442a
Weedy check	-	251b	143d
Diclofop-methyl	2	500a	366abc
Manual	2	466a	419ab
Diclofop-methyl	4	426a	317c
Manual	4	431a	322c
Diclofop-methyl	5	412a	305c
Manual	5	486a	341b

[1] Numbers within columns followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test. (From O'Donovan and O'Sullivan, 1982a).

The information to date indicates some variation in the time of onset of wild oat competition from country to country, region to region, and year to year. A number of factors such as crop species, wild oat density, and environmental conditions appear to play an important role in the process. Care should be taken, therefore, when interpreting data from specific experiments, and conclusions should not be drawn without taking into consideration the conditions under which the experiments were conducted. Further research in this area should concentrate on determining the extent to which some of these factors influence the "critical period" of wild oat competition.

Effect of Time of Emergence of Wild Oats Relative to the Crop

It was shown that seeding cereal crops two weeks prior to seeding wild oats reduced wild oat seed production by 63% (Thurston, 1962). In a similar study with barley and wild oats, McBeath *et al.* (1970) found that "the first species to germinate gained the upper hand and became better established and more competitive." O'Donovan and O'Sullivan (1982b) found that barley and wheat yield loss was most severe when the wild oats (115 plants/m^2) emerged before the crop (Fig. 5). Yield loss diminished when wild oats emerged after the crop. The mathematical models developed by Dew (1972) and Dew and Keys (1976) may vary, therefore, depending on the time of emergence of the wild oats relative to the crop.

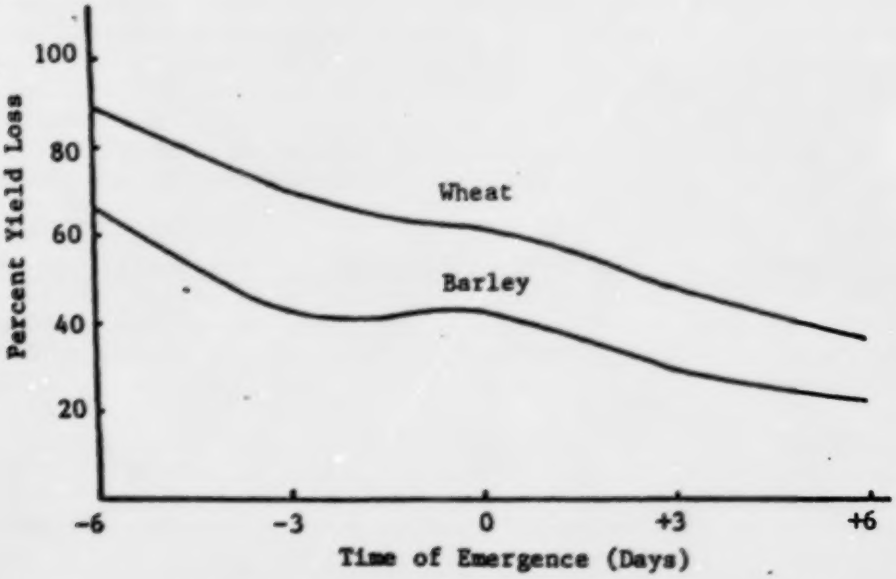

Fig. 5 Influence of relative time of emergence of wild oats (-before the crop, + after the crop) on yield loss of barley and wheat. (From O'Donovan and O'Sullivan, 1982b).

Effect of Crop Species and Cultivars

The "indices of competition" (Table 1) developed by Dew (1972) and Dew and Keys (1976) are indicative of the competitive abilities of the various crops. The lower the index, the greater the competitive ability of the crop. Barley is, therefore, most competitive, followed by rapeseed, wheat and flax (Fig. 4). This is in general agreement with previous studies. Barley was found to compete better with wild oats than other cereals (Chancellor and Peters, 1970; Pavlychenko and Harrington, 1934), while flax was less competitive than wheat (Bowden and Friesen, 1967). Cultivated oats was similar to wheat (Dew, 1979).

Little information is available on competitive differences between crop cultivars to wild oats. Generally, winter cereals are more competitive than spring cereals due to the fact that they become established before wild oats emerge. Different cultivars of winter wheat appeared to vary in their competitiveness to cultivated oats (Holmes and Pfeiffer, 1962). Similarly, two spring wheat cultivars differed in their competitive ability in equal stands of wheat and wild oats but differences diminished as wild oat density increased (Henson and Jordan, 1982). Further research is necessary to determine the competitiveness of different crop cultivars with wild oats.

Effect of Crop Density

Increasing the seeding rate of cereal crops reduced competition due to wild oats by suppressing wild oat infestations (Bate et al., 1970; McCurdy, 1955; Molberg and Legget, 1955). Higher seeding rates of wheat and barley reduced wild oat seed production (Chancellor and Peters, 1970) while higher seeding rates of wheat reduced wild oat dry weight as well as seed production (Radford et al., 1980).

Crop density may affect the "indices of competition" developed by Dew (1972) and Dew and Keys (1976) and, therefore, alter the economic threshold for control of wild oats with herbicides. The importance of wheat density in the assessment of wild oat competition was determined by Carlson et al. (1981). Using the relative proportion of wild oats in the total stand to develop a model to predict wild oat competition, it was found that the shape and slope of competition curves vary at different wheat density levels (Fig. 6). On average, over the range of wheat and wild oat densities tested, doubling the wheat density essentially doubled the number of wild oat plants required to cause a given reduction in yield. The model was used to evaluate the economics of wild oat control at various wheat and wild oat densities with a postemergence herbicide. Little or no similar information is available, however, on other crop species, indicating a need for further research in this area.

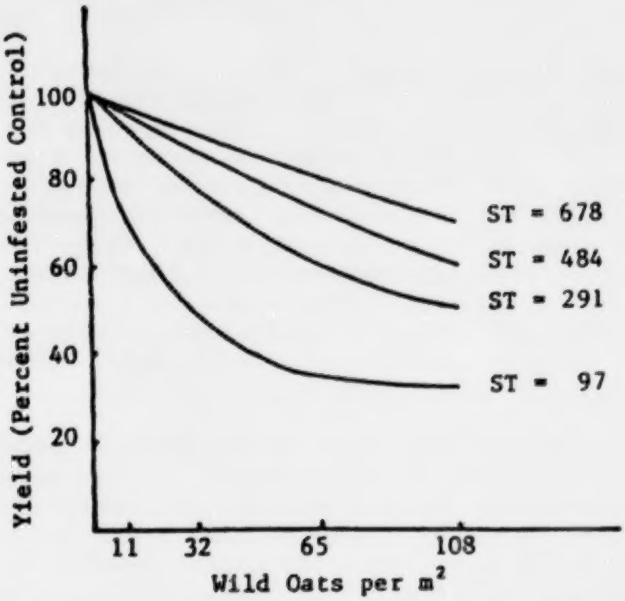

Fig. 6 Wild oat competition curves at varied wheat stands. ST = wheat plants per m^2. (Adapted from Carlson et al., 1981).

Effect of Edaphic and Climatic Factors

A number of studies have been conducted to determine the influence of soil nutrients on wild oat competition. Most of these have involved applications of nitrogen and phosphorus fertilizer and reports vary as to whether fertilizer applications benefit the crop, or the weed, or have no effect. In several studies (Bell and Nalewaja, 1968a; Bowden and Friesen, 1967; McBeath et al., 1970; Sexsmith and Russell, 1963), added nitrogen increased the growth of cereals and wild oats but did not affect the competitive balance between the crops and the weed. However, in another study, the application of nitrogen in wheat resulted in increased yield loss due to wild oat competition (Carlson and Hill, 1982). Similarly, in flax, nitrogen fertilizer increased the competitiveness of wild oats and adversely affected the flax yield (Sharma et al., 1977a). In general, it appears that the effect of nitrogen fertilizer on wild oat competition varies with the weed density and the crop species.

Studies by Sharma et al., (1977a) indicated that method of placement of phosphorus was important in determining the response of the crop and the weed to the nutrient. Drilling phosphorus fertilizer with the barley seed enhanced uptake of both phosphorus and nitrogen by the cereal and increased seed yield (Table 3). Such efforts were not as pronounced when phosphorus was applied with wild oat seeds as to wild oats mixed with barley (Table 3).

Table 3 Influence of different methods of phosphorus placement on seed yield and uptake of phosphorus and nitrogen by barley and wild oats.

	BARLEY			WILD OATS		
P FERTILIZER PLACEMENT	SEED YIELD[1] g/m^2	N UPTAKE kg/ha	P UPTAKE kg/ha	SEED YIELD[1] g/m^2	N UPTAKE kg/ha	P UPTAKE kg/ha
Control - no fertilizer	169	68	7	56	55	4
Drilled with barley	437	163	12	26	24	3
Drilled with barley and wild oats	294	158	12	60	44	5
Drilled with wild oats	210	119	9	85	80	7
LSD 5%	83	62	4	30	36	NS

[1] Data averaged from two locations at two rates of phosphorus. (Adapted from Sharma *et al*., 1977a).

In another study, method of nitrogen placement had little effect and benefited both the wild oat and the crop. These differences between nitrogen and phosphorus placement are believed to be related to the relative immobility of phosphorus in the soil compared to nitrogen. The studies of Sexsmith and Russell (1963) and Sharma *et al.* (1977a) demonstrate the importance of applying adequate phosphorus fertilizer with the seed in a cropping program where wild oats are known to be a problem.

Little is known about the effect of other soil nutrients on wild oat competition indicating a need for research in this area.

Available *soil moisture* is probably the most important resource of competing plants. Since wild oats possess an extensive root system (Pavlychenko and Harrington, 1934), they can compete effectively for moisture with other plants. Suggestions have been made that wild oats may be more tolerant to soil moisture than some crop plants (Sharma *et al*., 1977b; Thurston, 1962). There is a need for further information, however, on the relative ability of wild oats to compete with various crops and crop cultivars under different soil moisture regimes.

Little information is available on the effects of *soil pH* on wild oat competition. Thurston (1962), however, found that wild oats grew better than barley on acid soils.

Light can also be an important factor in competition, especially in situations where the weed emerges before the crop. The tall-growing wild oats may compete for light more effectively than low-growing crops such as flax. However, little is known about the relative efficiency of wild oats as a competitor with various crops and cultivars for light. A recent study from Germany (Wimschneider and Bachtalor, 1979) illustrates the importance of light as a factor in wild oat competition with two spring wheat cultivars. The wild oats reduced the light available to the wheat by 16 to 37%. A long-strawed cultivar (Janus) with horizontally oriented leaves proved a stronger competitor with wild oats than a short-strawed erect-leaved cultivar (Famos).

CONCLUSIONS

It is evident from this review that wild oats can seriously reduce crop yields and cause extensive crop losses. The models produced by Dew (1972), Dew and Keys (1976) and Carlson et al., (1981) provide a means of predicting yield losses and offer an opportunity to the producer to gain an insight into the cost-effectiveness of wild oat control. There is a considerable amount of data on yield reductions due to different densities of wild oats. However, there are a number of factors which play a large part in determining the extent of wild oat competition. Future research emphasis should be placed on assessing the relative importance of environmental factors, such as soil moisture, soil nutrient status, and light on the time of onset and extent of wild oat competition in various crops and cultivars. There is also a need for more research on the effects of wild oats on crop quality, especially in the case of rapeseed. In conclusion, the following observation would appear to be relevant to the current state of the art with regard to wild oat competition. "Scientists have diligently described the result of weed competition, but have not been equally attentive to analyzing why observed effects occur for specific crop-weed interactions or environmental changes...." (Zimdahl, 1980).

REFERENCES

Alex, J. F. 1966. Survey of weeds of cultivated land in the prairie provinces. Can. Dept. Agr., Regina, Saskatchewan.

Bate, P. G., J. G. Elliott, and B. J. Wilson. 1970. The effect of barley population and row width on the growth of Avena fatua. Brit. Weed Contr. Conf. Proc. 10:826-830.

Bell, A. R., and J. D. Nalewaja. 1968a. Competition of wild oat in wheat and barley. Weed Sci. 16:505-508.

Bell, A. R., and J. D. Nalewaja. 1968b. Competitive effects of wild oat in flax. Weed Sci. 16:501-504.

Bell, A. R., and J. D. Nalewaja. 1968c. Effect of duration of wild oat competition in flax. Weed Sci. 16:509-512.

Bleasdale, J. K. A. 1960. Studies on plant competition, p. 133-142. In J. L. Harper (ed.) The Biology of Weeds. Blackwell Scientific Publications, Oxford.

Bowden, B. A., and G. Friesen. 1967. Competition of wild oats (Avena fatua L.) in wheat and flax. Weed Res. 7:349-359.

Carlson, H. L. and J. E. Hill. 1982. Plant density relationships of wild oat (Avena fatua L.) competition with spring wheat. Weed Sci. Soc. of Am. Abstr.

Carlson, H., J. Hill, and K. Baghott. 1981. Wild oat competition in spring wheat. Ann. Calif. Weed Conf. Proc. 33:13-24.

Chancellor, R. J., and N. C. B. Peters. 1970. Seed production by Avena fatua populations in various crops. Brit. Weed Contr. Conf. Proc. 10:7-11.

Chancellor, R. J., and N. C. B. Peters. 1974. The time of onset of competition between wild oats (Avena fatua L.) and spring cereals. Weed Res. 14:197-202.

Chancellor, R. J., and N. C. B. Peters. 1976. Competition between wild oats and crops, p. 99-112. In D. P. Jones (ed.) Wild oats in world agriculture. Agr. Res. Coun., London.

Chow, P. N. P., and D. G. Dorrell. 1979. Wild oats effect on quality and quantity of flax and rapeseed. Can. Agr. 24(4):18-19.

Dew, D. A. 1972. An index of competition for estimating crop loss due to weeds. Can. J. Plant Sci. 52:921-927.

Dew, D. A. 1975. Effect of time of hand removal for wild oats in barley, p. 623-624. In Res. Rep. Can. Weed Comm. (West. Sect.).

Dew, D. A. 1976. Effect of time of removal of wild oats in rape, p. 593-594. In Res. Rep. Can. Weed Comm. (West. Sect.).

Dew, D. A. 1977. Effect of time of hand removal for wild oats in wheat, p. 195-196. In Res. Rep. Can. Weed Comm. (West. Sect.).

Dew, D. A. 1978a. Estimating crop losses caused by wild oats, p. 15-18. In Wild Oat Action Comm. Sem. Proc., Regina, Saskatchewan.

Dew, D. A. 1978b. Effect of time of removal of wild oats in flax, p. 281. In Res. Rep. Expert Comm. on Weeds (West. Canada).

Dew, D. A. 1979. Effect of density of wild oats on yield of oats, p. 229-230. In Res. Rep. Expert Comm. on Weeds (West. Canada).

Dew, D. A., and C. H. Keys. 1976. An index of competition for estimating loss of rape due to wild oats. Can. J. Plant Sci. 56: 1005-1006.

Friesen, G., L. H. Shebeski, and A. O. Robinson. 1960. Economic losses caused by weed competition in Manitoba grain fields. II. Effect of weed competition on the protein content of cereal crops. Can. J. Plant Sci. 40:652-658.

Friesen, H. A. 1973. Identifying wild oats yield losses and assessing cultural control methods, p. 20-25. In Proceedings, Action Proposals and Programs of "Let's Clean up on Wild Oats" Seminar, Saskatoon, Saskatchewan.

Hamman, W. M. 1979. Field confirmation of an index for predicting yield losses of wheat and barley due to wild oat competition. Can. J. Plant Sci. 59:243-244.

Henson, J. F., and L. S. Jordon. 1982. Wild oat (Avena fatua) competition with wheat (Triticum aestivum and Triticum turgidum durum) for nitrate. Weed Sci. 30:297-300.

Holmes, H. M. and R. K. Pfeiffer. 1962. Some aspects of the use of barban for wild oat control in winter wheat. Weed Res. 2: 110-121.

Keys, C. H. 1975. Effect of wild oat competition (populations) on rapeseed production, p. 629. In Res. Rep. Can. Weed Comm. (West. Sect.)

Lee, G. A., M. E. Coleman-Harrell, and W. S. Belles. 1979. Influence of densities and exposure durations of wild oat (Avena fatua L.) populations on the yields of spring wheat (Triticum aestivum L.). Weed Sci. Soc. of Am. (Abstr.)

McBeath, D. K., D. A. Dew, and H. A. Friesen. 1970. Competition between barley and wild oat as affected by nitrogen, barban and time of seeding. Can. J. Plant Sci. 50:541-550.

McCurdy, E. V. 1955. Cultural and cropping practices to control wild oats, p. 73. In Res. Rep. 12th North Centr. Weed Contr. Conf.

McNamara, D. W. 1976. Wild oat density and the duration of wild oat competition as it influences wheat growth and yield. Austr. J. Exp. Agr. Anim. Husb. 16:402-406.

Molberg, E. S., and H. W. Leggett. 1955. Cultural methods for wild oat control, p.76. In Res. Rep. 12th North Centr. Weed Contr. Conf.

Nalewaja, J. D. 1977. Wild Oats: global gloom. West. Soc. of Weed Sci. Proc. 30:21-32.

Nieto, J. H., M. A. Brondo, and J. T. Gonzalez. 1968. Critical periods of the crop growth cycle for competition from weeds. PANS (C). 14:159-166.

O'Donovan, J. T., and P. A. O'Sullivan. 1982a. Influence of manual and herbicide (diclofop-methyl) removal of wild oats at various leaf stages on yield of barley and heat, p. 188. In Res. Rep. Expert Comm. on Weeds (West. Canada).

O'Donovan, J. T., and P. A. O'Sullivan. 1982b. Influence of time of emergence of wild oats relative to barley and wheat on yield of barley and wheat, p. 187. In Res. Rep. Expert Comm. on Weeds (West. Canada).

Pavlychenko, T. K., and J. B. Harrington. 1934. Competitive efficiency of weeds and cereal crops. Can. J. Res. 10:77-94.

Radford, B. J., B. J. Wilson, O. Carledge, and F. B. Watkins. 1980. Effect of wheat seeding rate on wild oat competition. Aust. J. Exp. Agr. Anim. Husb. 20:77-81.

Scragg, E. B. 1980. Cost effective weed control in spring barley in the North of Scotland, p. 69-76. In Brit. Crop Prot. Conf. - Weeds Proc.

Scragg, E. B., and A. D. McKelvie. 1976. The effect of certain species of weeds on the grain yield of spring barley. Ass. Appl. Biol. Proc. 83:335-338.

Sexsmith, J., and G. C. Russell. 1963. Effect of nitrogen and phosphorus fertilization on wild oats and spring wheat. Can. J. Plant Sci. 43:64-69.

Sharma, H. C., and J. H. Hunter. 1974. Effect of time of removal of wild oats on competition in wheat, p. 13. In Res. Rep. Wheat Comm. (West. Sect.)

Sharma, M. P., D. K. McBeath, and W. H. Vanden Born. 1977a. Wild Oats: Herbicide - Fertilizer Interactions, p. 80. In Res. Rep., Univ. of Alberta, Edmonton, and Agr. Can. Res. St., Lacombe.

Sharma, M. P., D. K. McBeath, and W. H. Vanden Born. 1977b. Studies on the biology of wild oats. II. Growth. Can. J. Plant Sci. 57:811-817.

Thurston, J. M. 1962. The effect of competition from cereal crops on the germination and growth of Avena fatua L. in a naturally infested field. Weed Res. 2:192-207.

Wilson, B. J., and N. C. B. Peters. 1982. Some studies of competition between Avena fatua L. and spring barley I. The influence of A. fatua on yield of barley. Weed Res. 22:143-148.

Wimschneider, W., and G. Bachtalor. 1979. Studies on the competition for light between Avena fatua L. and several varieties of spring wheat, p. 249-256. In EWRS Symp. on the Infl. of Diff. Factors on Develop. and Contr. of Weeds Proc.

Wood, H. E. 1953. The occurrence and problem of wild oats in the Great Plains Region of North America. Weeds 2:292-294.

Zimdahl, R. L. 1980. Weed-Crop Competition, A Review. Int. Plain Prot. Center, Oregon State Univ., Corvallis. 196 p.

CULTURAL CONTROL OF WILD OATS

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ABSTRACT

A high degree of control of wild oats can be achieved with cultural methods. Success with cultural methods varies with climatic conditions and may change from region to region and year to year. Careful management is a priority. Delayed seeding results in a consistently high degree of control of wild oats, but can also result in significant losses in grain yield and quality. The optimum in cultural control is a program consisting of weed free seed, careful selection of crop type and tillage equipment, and judicious use of summerfallow and fertilizer in combination with delayed seeding. The optimum in control of wild oats is a combination of cultural and chemical control methods.

Cultural practices for the control of wild oats have been investigated by various research institutions in the prairie provinces for the past 50 years. However, since the advent of selective herbicides, the research effort with cultural control methods has decreased substantially. Prior to the introduction of herbicides, around 1960, most producers employed one or more cultural methods in their cropping system to achieve some measure of control. The research results and producer experience indicate that cultural practices to control wild oats have some merit and a high degree of control can be achieved, provided considerable attention is devoted to accurate timing combined with selection of proper crop type and tillage equipment. Success with cultural methods is often influenced by factors over which the producer has little or no control. Fluctuating weather conditions often determine the success or failure of a particular practice from year to year, or region to region. In addition, grain quotas and the price for both grain and livestock often dictate which crop must be grown to keep the farm economically viable. In spite of these factors, several cultural practices have been developed which should be considered as effective and economical alternatives in an integrated program for the control of this problem weed.

CLEAN SEED

Cultural control of wild oats should begin with weed free seed. Although clean seed is of primary importance it is being ignored by many farmers. Seed drill surveys conducted in the three prairie provinces indicate that on an average, 30% of the seed wheat graded rejected.

The quality of seed has improved over the years. In Alberta the percent of rejected samples decreased from 51% in 1949 to 30% in 1968 (Friesen, 1973), and in Manitoba it decreased from 44% in 1976 to 30% in 1981 (Hunter, 1982). Seed samples cleaned in the elevator decreased from 36% in 1976 to 15% in 1981. The type of seed cleaning facility is important in the quality of the seed sample (Table 1). Seventy percent of the samples cleaned in the elevator graded rejected.

Table 1 Quality of seed cleaning done by various facilities in Manitoba

	%		Quality of cleaning method (%)		
Type of cleaning	1976	1981	#1 seed	#2 seed	rejected
Stationary plant	39	67	53	27	18
Farm	20	14	31	30	40
Mobile plant	3	3	8	30/31?	62
Elevator	36	15	9	21	70

(From Manitoba Agriculture Farm Facts, Agdex 110, January 1982)

In a survey in Saskatchewan (Austenson, 1973), elevator cleaned wheat seed contained 110 weed seeds per kg with 45% of the samples grading rejected compared to certified seed wheat with 1 weed seed per kg and no samples graded rejected.

Weed free seed should be a major consideration in any wild oat control program. A single wild oat plant can produce 500 seeds. Therefore, one wild oat seed in a kilogram of wheat seed could produce five wild oat seeds for every square meter. A few dollars spent on weed free seed will be more than compensated for in reduced weed control costs.

DELAYED SEEDING

Delayed seeding using an early maturing crop has been the most widely practiced cultural method. Most wild oats that germinate during the growing season do so before the end of May. Shallow cultivation in eary spring will increase the soil temperature and promote early germination of wild oats. Tillage 10 to 14 days later, or when the wild oats are 7 to 10 cm tall, will destroy the majority of the seedlings. Control is considerably reduced if the wild oats are less than the 2 to 3-leaf stage, soil conditions are cool and moist or a rain occurs shortly after cultivation. Without early cultivation, seeding may have to be delayed an additional 7 to 10 days for the wild oats to reach the desired growth stage (Banting, 1977).

The effect of delayed seeding on reducing wild oat populations was determined in a cooperative experiment run at seven Agriculture Canada Research Stations from 1952-57 (Table 2). All stations, except Regina and Brandon, showed over 70% reduction in wild oat population with a trend to increased yields on the cleaner late-seeded barley. At Brandon and Regina, wet springs in several years reduced the effectiveness of the tillage operations considerably. In wheat, this practice controlled over 80% of the wild oats. However, the late seeding reduced crop yields by about 40% (Friesen, 1973).

Table 2 Effect of delayed seeding on yields of wheat and barley and wild oat control in the prairie provinces, 1952-1957

		Grain (tonnes/ha)		Wild oat (plants/m^2)		Wild oat
Location	No. of years	Normal seeding	Delayed seeding	Normal seeding	Delayed seeding	Percent control
			Barley			
Brandon	5	1.73	1.57	49	43	12.2
Indian Head	5	0.81	1.13	186	52	71.8
Melfort	4	1.46	1.94	60	13	78.0
Regina	5	1.46	0.81	40	32	23.0
Swift Current	2	-	-	52	5	90.9
Lethbridge	4	1.62	1.57	19*	1*	93.8
Lacombe	5	2.00	2.32	183	55	70.1
			Wheat			
Indian Head	5	2.21	1.41	38	7	81.2
Regina	5	0.73	0.54	202	11	94.7
Swift Current	2	-	-	39	5	93.9
Lethbridge	4	1.34	1.01	44*	2*	94.6

*Culm counts, not plant counts
(From Can. Dept. Agric. Publ. 1044, 1959).

Delayed seeding has disadvantages, both agronomic and economic. Early spring cultivation has a significant effect on promoting wild oat germination; by breaking the surface crust the soil warms up quickly. However, this tillage operation combined with a second one 10-14 days later contribute to drying of the seedbed and a breakdown in structure of the soil surface. This can become even more pronounced if attempts are made to grow out two flushes of wild oats prior to seeding.

Although delayed seeding is considered to be one of the best methods of cultural control, an eight-year study conducted under weed free conditions at Regina and Indian Head indicates that delayed seeding may not be an economical method of controlling wild oats (Table 3). The reduction in yield and/or lower grades from the later seeded crops resulted in a high sacrifice in economic returns. The higher returns from early seeding more than compensated for the cost of a wild oat herbicide (Hunter, 1980).

Table 3 Average income[a] from three dates of seeding wheat and barley on weed free plots

Seeding date	Yield T/ha	Yield \$/ha[b]	Loss \$/ha
Wheat			
Normal	3.14	429	0
Delayed 10 days	3.06	410	19
Delayed 20 days	2.65	336	33
Barley			
Normal	3.44	382	0
Delayed 10 days	3.01	333	50
Delayed 20 days	3.17	332	50

[a] Based on Canadian Wheat Board final price, (1975-78)

[b] Values rounded to the nearest dollar

Delayed seeding can be successfully used in some fields. Fields known to have a wild oat problem should be left to the last to seed. If seeding is delayed due to a large number of acres to seed or wet weather etc., cultural control of wild oats may be very good. However, intentionally delaying seeding may not be an economically sound practice.

CROP COMPETITION

Yield losses due to competition from wild oats is one of the most serious problems facing grain producers in western Canada. Weed surveys in Alberta (Thomas, 1978), Saskatchewan (Thomas, 1979), and Manitoba (Thomas and Wise, 1981), indicate that 56 to 73% of the fields are infested with wild oats at an average density of 14 to 19 wild oat plants/m^2 (Table 4). Dew (1972) reported that as few as 5 wild oat plants/m^2 reduced the yields of wheat, barley and flax. Yield losses will vary depending on when the wild oats emerge relative to the emergence of the crop. In a four year study, J.H. Hunter (unpublished data) found that when 50 wild oat plants/m^2 emerged one week before wheat and flax, yield reductions were 19 and 27% greater than when the wild oats emerged on week after the crops (Table 5). Cultural practices such as well-timed tillage, shallow seeding and fertilizer with the seed help to get the crop started ahead of the wild oats.

Table 4 Percent of fields in the prairie provinces infested with wild oats

Province	Year	Field infested with wild oats (%)	Density of wild oats (no./m^2)
Alberta	1977	56	19
Saskatchewan	1979	70	14
Manitoba	1981	73	19

Table 5 The effect of the relative date of emergence of wild oats on the yield of wheat and flax

Date of emergence of wild oats[a]	Wheat		Flax	
	Yield (T/ha)	Loss (%)	Yield (T/ha)	Loss (%)
One week before crop	1.97	26	0.45	63
With crop	2.46	10	0.49	60
One week after crop	2.53	7	0.78	36
Weed free check	2.76	0	1.22	0

[a]Density of 50 plants/m^2

The relative competitive ability of wheat, barley, rapeseed and flax at several densities of wild oats is shown in Table 6. Barley and rapeseed were more competitive at all densities than wheat, while flax was the poorest competitor (Dew, 1972).

Table 6 Effect of wild oat populations on yield

Wild oats/m^2	Loss in grain yield (%)[a]			
	Wheat	Barley	Rapeseed	Flax
0	0	0	0	0
11	10.7	7.3	8.0	19.0
22	15.0	10.3	11.3	27.0
32	18.7	12.7	14.0	33.0
54	24.0	16.3	18.0	42.3
75	28.3	19.3	21.3	50.3
108	34.0	23.0	25.7	60.0
161	41.7	28.3	31.3	73.7
215	48.0	32.7	36.3	-

[a]Weed-free yield of the crops was 2.0, 1.6, 1.9 and 1.7 tonnes/ha, respectively.

Crop selection is an important consideration. Barley and rapeseed can be expected to show much lower yield reductions than flax. Barley is the most competitive of the commonly grown annual crops, however, selection of the proper type and variety is important. Six-row barley will germinate as much as two days sooner than the two-row types. More rapid germination and emergence combined with the greater leaf area at all growth stages make the six-row types more competitive and should be beneficial in combating the early growth competition as suggested by Bowden and Friesen (1967).

Choice of variety can have a significant effect on yield, particularly when delayed seeding is practiced. Cooperative long-term variety tests across the prairies show that early maturing barley varieties such as Olli and Gateway yielded 20 to 25% less than the commonly grown, medium maturing varieties when planted at normal seeding dates (Kirkland, 1978). Therefore, variety selection is important in establishing an economically sound control method.

CROP ROTATION

Fall-seeded crops such as fall rye and winter wheat can be used to advantage to reduce wild oat stands in areas where these crops can be grown. Later germinating wild oats which emerge following the mid-August to September seeding period will be killed by fall frost. Fall-seeded crops begin growth early in the spring and tend to smother the wild oats which germinate later, provided a high level of winter survival of the crop has been obtained. Fall rye is generally more vigorous and competitive than winter wheat.

Rotation of annual crops as a method of cultural control has been rather ineffective in reducing wild oat infestations. Fall-seeded crops and perennial forages compete more vigorously and can reduce wild oat infestations. Perennial forage crops tend to be less effective than fall-seeded crops and, because of the relatively long dormancy of wild oats, the land must be left in forages for a number of years. In many areas the production of forage is neither feasible or economically advantageous.

Lacombe, Indian Head and Brandon Research Stations have compared grain-forage with straight grain rotations for 40 years (Table 7). Delayed seeding resulted in the best control of wild oats followed closely by fall-sown crops. The wheat-fallow rotation remained heavily infested with wild oats (Friesen, 1973).

Table 7 Effect of four different six-year rotations on wheat yields and wild oat populations

Rotation[a]	Wheat yield (T/ha) 1953	Wheat yield (T/ha) 1958	Reduction of wild oats (%)
1 Delayed seeded crops	1.1	0.6	87
2 Fall-sown crops	1.1	0.8	66
3 Forage crops	1.0	0.6	47
4 Fallow-wheat crops	1.1	0.4	4

[a] 1 Wheat - barley (delay seed) - barley (delay seed) - fallow - barley (delay seed) - wheat
2 Wheat - fallow + seed fall rye - fall rye - fallow + seed fall rye - fall rye - wheat
3 Wheat + seed brome - brome - brome - brome + break in June - barley (delay seed) - wheat
4 Wheat - fallow - wheat - fallow - wheat - wheat

SEEDING RATE AND DEPTH

Depth of seeding is a major consideration in establishing a competitive crop. Deep seeding results in slow germination and emergence and the crop will be less competitive with wild oats. Seeding depth of cereals is most critical for barley, followed by wheat. Oats and rye are less affected (Johnson, 1977).

Summerfallowing is not an effective method of controlling wild oats. Banting (1962) found that it took two consecutive years of fallow to greatly reduce the wild oat seed density in the soil. However, he also found that one year of the summerfallow followed by delayed seeding reduced a heavy wild oat infestation to less than 5% of the original population.

Gobel (1935) and Pfeiffer and Holmes (1961) found that although heavier than usual seeding rates increased the yield of grain, the wild oats were only partially checked. Heavier seeding rates of wheat and barley reduced the number of wild oat plants by 35 and 50% respectively, when seeded at normal seeding dates and by 28 and 35% for delayed seeding. Seeding rates used were 65 and 135 kg/ha for wheat and 80 and 160 kg/ha for barley (Friesen, 1973). Seeding rate is an important part of a control program but alone it will not effectively control wild oats.

POST SEEDING CULTIVATION

Sometimes when the wild oats start growth ahead of the crop, cultivation can be carried out after seeding. The crop should be seeded a little deeper than usual and cultivation should be completed before the grain sprouts are 2 cm in length. A rod weeder is the recommended implement but harrows can be used. Excess trash, shallow seeding, compacted soil, or cool, wet weather may make post-seeding cultivation impossible.

FALL TILLAGE

Fall tillage may be useful in promoting the germination of wild oats after harvest if the seeds have been exposed to warm dry weather for two or three weeks. Its value is questionable if the weather is cool and moist. If tillage is used, a shallow coverage of the seed that leaves the stubble standing is desired (Banting, 1977).

GREENFEED CROPS

Greenfeed crops, such as oats, can be used to help control wild oats in low spots or other heavily infested areas. Wild oats should be cut when the panicle starts to emerge from the sheath to prevent maturation of the seed on the cut plants. To prevent regrowth the area should be tilled and a program of partial summerfallow carried out.

BURNING STRAW

Burning of straw or stubble to destroy wild oat seeds is not a recommended practice. Under prairie conditions, the value of a trash cover in reducing erosion, maintaining organic matter, and increasing the amount of snow cover, far outweighs the reduction in wild oat seeds. However, around potholes or sloughs where unmanageable amounts of trash may interfere with seed placement in the spring, burning may sometimes be practical. Molberg and Banting (1973) found that by burning windrowed straw immediately after harvest about 80% of the wild oat seed was destroyed. When burning was delayed for three weeks, or until the following spring, only about 60% of the seed that remained on the soil surface was destroyed.

FERTILIZER

Phosphate fertilizer can advance crop maturity and is helpful with delaying seeding (McFadden, 1970). Nitrogen applied in fall or early spring can stimulate germination of wild oat seeds (Sexsmith and Pittman, 1963). Nitrogen can also increase the competitiveness of wild oat plants (Sexsmith and Russell, 1963). Nitrogen had only a slight effect on the seed yield of wild oats (Bowden and Friesen, 1967). Yields of wheat infested at varying levels of wild oats were generally higher on fertilized than on unfertilized plots, however, yield increases due to control of wild oats were six times greater than for fertilizer done (Table 8).

Table 8 Effect of fertilizer and wild oats on yield of wheat

Fertilizer[a] (kg/ha)	Wild oats (no./m^2)	Wheat yield (T/ha)
0	84	0.96
56	84	1.10
0	0	1.85
56	0	1.87

[a] 11-48-0

REFERENCES

Austenson, H.M. 1973. Comparing quality of certified and elevator-cleaned seed of wheat and barley, 1971-72. Univ. Saskatchewan, Extension Publ. 237.

Banting, J.D. 1962. The dormancy behavior of Avena fatua in cultivated soils. Can. J. Plant Sci. 42: 22-39.

Banting, J.D. 1973. How wild oats grow. Let's clean up wild oats seminar (Saskatoon, Sask.), Proc. 16-19.

Banting, J.D. 1977. Growth habit and control of wild oats. Agric. Can. Publ. 1531.

Bowden, B.A., and G. Friesen. 1967. Competition of wild oats (Avena fatua L.) in wheat and flax. Weed Res. 7: 349-359.

Dew, D.A. 1972. An index of competition for estimating crop loss due to weeds. Can. J. Plant Sci. 52: 921-927.

Friesen, H.A. 1973. Identifying wild oat yield losses and assessing cultural control methods. Let's clean up wild oats seminar (Saskatoon, Sask.), Proc. 20-25.

Gobel, G.L. 1936. Relation between rate of seeding and yield of cereal crops in competition with weeds. Sci. Agr. 16: 165-168.

Hunter, J.H. 1980. An economic assessment of delayed seeding for control of wild oats. North Central Weed Control Conf. Proc., 35: 39.

Hunter, J.H. 1982. Weed free seed is the first step in a weed control program. Grainews 12: 23.

Johnson, W.E. 1977. The integration of crop production practices in western Canada. Sask. Dept. Agric. Publ.

Kirkland, K.J. 1978. Control of wild oats by cultural methods. Wild oat action committee, Seminar '78 (Regina, Sask.), Proc. 39-49.

McFadden, A.D. 1970. Influence of seeding dates, seeding rates and fertilizer on two cultivars of barley. Can. J. Plant Sci. 50: 693-699.

Molberg, E.S., and J.D. Banting. 1973. Effect of burning wheat stubble on the viability of wild oat seeds. Can. Weed Comm. Res. Rep. 352-353.

Pfeiffer, R.K., and H.M. Holmes. 1961. A study of the competition between barley and wild oats as influenced by barley seed rate, nitrogen level and barban treatment. Weed Res. 1: 15-18.

Sexsmith, J.J., and U.J. Pittman. 1963. Effect of nitrogen fertilizers on germination and stand of wild oats. Weeds 11: 90-101.

Sexsmith, J.J., and G.C. Russell. 1963. Effect of nitrogen and phosphorus fertilization on wild oats and spring wheat. Can. J. Plant Sci. 43: 64-69.

Thomas, A.G. 1978. Surveys of wild oats and other weeds. Wild oat action committee, Seminar '78 (Regina, Sask.), Proc. 11-14.

Thomas, A.G. 1979. Weed survey of cultivated land in Saskatchewan. Weed Survey Series Publ. 79-2, Regina Res. Stn.

Thomas, A.G., and R.F. Wise. 1982. Weed survey of cultivated land in Manitoba. Weed Survey Series Publ. 82-1 Agric. Can., Regina Res. Stn.

WILD OAT CONTROL WITH MINIMUM AND ZERO TILLAGE

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ABSTRACT

The concept of minimum and zero tillage grain production has been promoted as a means of conserving energy and for maintaining a crop cover to protect the soil from erosion. Research has shown that although crop yields can be maintained with reduced tillage, there is a change in the nature of weed problems. Under zero tillage, the numbers of wild oats are generally reduced, but the control of surviving plants with herbicides can be less effective than under normal agricultural situations.

The concept of minimum tillage was advocated in 1910 by E. C. Chilcott (Anon., 1979) for reducing crop production costs without substantially reducing yields. During the dry 1930s, minimum tillage was practiced in the United States to reduce the number of tillage operations, to use the crop residue as a protection against soil erosion, and to increase water infiltration.

Although interest in zero tillage grew in Europe and the United States during the early fifties, no serious attempts were made to introduce the practice into western Canada until the late sixties. Mr. Jim McCutcheon at Homewood in Manitoba and Mr. Ed Keller of Leipzig, Saskatchewan, were among the first farmers in western Canada to successfully adopt the principle on a farm scale. In general, the present interest in Saskatchewan appear to favour a minimum tillage concept of crop production rather than one of zero tillage.

Today, the aim of zero tillage is to eliminate tillage to that required for opening a slot sufficiently wide for the placement of the seed into firm moist soil at a shallow uniform depth. Less than 15% of the soil surface should be disturbed by such planting, while weeds and volunteer grain are controlled entirely with herbicides. Under a minimum tillage system, up to three tillage operations are utilized for the managing of trash, for incorporating chemicals, for preparing a seed bed, and for seeding.

Studies have shown that under zero tillage situations moisture losses from the soil surface are reduced, that weed populations generally decrease when the soil is undisturbed (Banting, 1980; Cussans, 1975; Feldman and Reed, 1974; Fenster and Wicks, 1977; Pollard and Cussans, 1981; Pollard et al., 1982; Sharma et al., 1977).

Trials at both Melfort (Bowren, 1983) and Lethbridge (Lindwall, 1978), as well as other Research Stations across western Canada, have demonstrated that grain yields on chemical summerfallow were higher than on conventionally tilled fallow. The data from Melfort (Table 1) indicated that wild oat control was similar to that on conventionally tilled fallow.

Table 1 Methods of summerfallowing (14-year average, 1969-1982, Melfort)

Fallow treatment	Yield kg/ha[3] 14 yr. av.	Soil H_2O 0-122 cm Spring (cm)	Soil P 0-15 cm kg/ha[2]	Soil N 0-61 cm kg/ha[2]	Wild oat control 0-9 (9 = 100%) 1973-82 av.
Chemical	3446	58	62	89	8.8
Tillage	3289	56	61	84	8.7
Combination[1]	3328	54	57	73	8.6
L.S.D. 5%	82	1.9	N.S.	N.S.	N.S.
1%	116	2.6			
C.V.	3.5	4.5			

[1] One tillage June 1, and chemicals as required for weed control

[2] Average nutrients in soil in fall prior to seeding, 1969-81 average

[3] lb/ac = kg/ha x 0.891

Wild oats is one of the most common and troublesome weeds in field crops in western Canada (Banting, 1980; Betts, 1981; Dew, 1976; Thomas, 1979). Wild oats is a prolific producer of seeds that frequently shatter and fall to the soil surface before the crop is harvested (Banting, 1980; Fenster and Wicks, 1977; Frankton and Mulligan, 1970). On these shattered seeds the awns can twist and uncoil as the seeds become wet and then dry, which effectively imbed the seed into the soil. During the process of combining, this awn is removed from seed remaining on the wild oat plants so that this seed falls to the soil surface or is transported to the grain tank.

Feldman and Reed (1974) have studied the distribution of wild oat seeds during cereal crop swathing and combining and found that the greatest proportion of seeds found on the ground were the result of natural shatter. A significant amount of seed was also to be found in the grain tank. Wilson (1978) has similarly reported that if shattering of wild oat seed was prevented then the number of viable wild oat seeds in the soil decreased by 83% in the first year, and by 96% during the second year.

Of the seed remaining on the soil surface, some will be eaten by rodents, while others will rot, or germinate to be killed by drought or frost. Some will become dormant and retain their viability for several years (Banting, 1980).

Sharma et al. (1977) reported that fall tillage was better than spring tillage for stimulating wild oat seeds to germinate (Table 2). Cultivators appeared to stimulate germination to a greater degree than did harrows (Table 2). It was also noted (Sharma et al., 1977) that seeds exposed to warm dry weather after harvest were less dormant and if covered in the spring would show increased germination. Similar effect has been noted by Friesen (1973) and Lal and Steppuhn (1980).

Table 2 Effect of fall and spring tillage on wild oat germination

Time of tillage or implement	Wild oat emergence plants/m^2
Fall	276
Spring	108
Cultivators	218
Harrows	56

(Adapted from Sharma et al., 1977)

A tillage in combination with either fall or spring nitrogen treatments were beneficial in stimulating wild oat germination and thus their control. It was also observed (Sharma et al., 1977) that increased crop competition from phosphorus fertilizers applied with crop seed improved wild oat control (Table 3).

At Melfort, a 22-year study (Bowren, 1983) conducted on a continuous wheat rotation has led to the conclusion that neither fall tillage nor spring burning had any significant effect on wheat yield or on the control of wild oats. Treatments receiving higher annual applications of nitrogen showed, in recent years, a higher incidence of wild oats in the crop than in check treatments.

Table 3 Effect of phosphorus fertilizers with barley seed on yield barley and wild oat control

Rate of P (kg/ha) with seed		Seed yield 9/m^2			
		Lacombe		Cheddarville	
Lacombe	Cheddarville	Barley	Wild oats	Barley	Wild oats
0	0	164	55	173	57
10	20	436	20	284	38
20	40	520	17	307	28

(Adapted from Sharma *et al.*, 1977)

Wilson and Cussans (1975) observed the periodicity of seedling emergence of wild oats during the spring was unaffected by the time or type of cultivation, the age of the seed, or by burning the straw in the previous autumn.

Donaghy (1983) noted that, in Manitoba, weed populations did not differ after the first year of zero tillage, but changes were apparent during the second and third years, with a reduction in the numbers of wild oat plants (Table 4). However, it has been observed (McCutcheon, 1983) that zero tillage does not always control wild oats.

Table 4 Wild oat counts, plants/m^2, at two zero tillage sites in Manitoba

	Year 2		Year 3	
Site	Zero tillage	Conventional tillage	Zero tillage	Conventional tillage
Carman	2	6	1	14
Portage	23	39	27	75

(From Donaghy, 1983)

Bentley *et al.* (1978) noted that weed control in growing crops under zero tillage conditions was more difficult than under normal practices, with wild oats persisting in spite of the repeated use of postemergent herbicides. McCutcheon (1983) has also recorded that under zero tillage practices the control of wild oats with postemergent herbicides was variable. At Melfort, Bowren (1983), showed that wild oats persisted to a greater degree on zero tillage plots than on minimum tillage plots where triallate had been applied following seeding.

It would appear that not all is known about the effect of minimum and zero tillage on wild oat desiccation in western Canada, where the soil is frozen and covered with snow for much of the time between crops. With minimum tillage, conventional herbicide treatments are effective for wild oat control. With zero tillage, however, a number of factors must be considered in their use.

Traditional soil-incorporated herbicides cannot be used without tillage. Trash on the surface of untilled soil may impede the coverage of postemergent herbicides on the wild oat plants at the proper stage for control. Wild oats may have three or more leaves before they are exposed above the trash, thus making good coverage with early postemergent treatments difficult. Postemergent herbicides that kill wild oats from the three to five leaf stage will provide better control under these conditions. Pre-seeding spray treatments on zero till fields will kill exposed plants, however, the coverage of the plants must be complete and the plants should be dust free. A delay in germination of wild oats due to lower soil temperatures may reduce the effectiveness of this pre-seeding spray treatment. Small wild oats may not get sprayed and new germinations promoted by soil and trash disturbance at seeding time must be controlled later.

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REFERENCES

Anonymous. 1979. Zero tillage pays. Grain Growers. 100:126.

Banting, J. D. 1980. Growth habit and control of wild oats. Agr. Can. Pub. 1531.

Bentley, C. F., J. M. Crepin, and K. W. Domier. 1978. No till seeding yields equal to conventional seeding. Grain Growers. 100:126.

Betts, M. 1981. Green foxtail worst seed in Manitoba. Grain Growers. 100:100.

Bowren, K. E. 1983. Crop management studies, p. 79-82. In Research Highlights, Melfort Res. Sta., Melfort, SK.

Cussans, G. W. 1975. Weed control in reduced cultivation and direct drilling systems. Outlook on Agriculture. 8:240-242.

Dew, D. A. 1976. Distribution of some common weeds in Alberta. AGDEX 640-1.

Donaghy, D. I. 1983. Effect of zero tillage on weed populations in Manitoba. AGDEX 641. Personal communication.

Feldman, M., and W. B. Reed. 1974. Distribution of wild oat seeds during cereal crop swathing and combining. Paper presented at C.S.A.E. Annual Meeting, Laval Univ., Ste. Foy, Québec.

Fenster, C. R., and G. A. Wicks. 1977. Minimum tillage fallow systems for reducing wind erosion. Amer. Soc. Agr. Eng. Tran. 20:906-910.

Frankton, C., and G. A. Mulligan. 1970. Weeds of Canada. Can. Dep. Agr. 948:22-23.

Friesen, H. A. 1973. Identifying wild oat yield losses and assessing cultural control methods. "Let's Clean Up on Wild Oats" Seminar. Regina, SK.

Lal, R., and H. Steppuhn. 1980. Minimizing fall tillage on the Canadian prairies - a review. Can. Agr. Eng. 22:101-106.

Lindwall, C. W. 1978. Minimum tillage research in southern Alberta, p. 36-40. In Work Planning Meeting on Minimum Tillage, Proc. Saskatoon, SK.

McCutcheon, J. C. 1983. Personal communication.

Pollard, F., and G. W. Cussans. 1981. The influence of tillage on the weed flora in a succession of winter cereal crops on a sandy loam soil. Weed Res. 21:185-190.

Pollard, F., S. R. Moss, G. W. Cussans, and R. J. Frond-Williams. 1982. The influence of tillage on the weed flora in a succession of winter wheat crops on a clay loam soil and a silt loam soil. Weed Res. 22:129-136.

Sharma, M. P., D. K. McBeath, and W. H. Vanden Born. 1977. Wild oat herbicide-fertilizer interactions. Agr. Can. and Univ. Alberta Rep. 1977.

Thomas, A. G. 1979. Weed survey of cultivated land in Saskatchewan. Agr. Can. Res. Sta., Regina, SK. October 1979.

Wilson, B. J., and G. W. Cussans. 1975. A study of the population dynamics of Avena fatua L. as influenced by straw burning, seed shedding and cultivation. Weed Res. 151:249-258.

Wilson, B. J. 1978. The long term decline of a population of *Avena fatua* L. with different cultivations associated with spring *barley cropping*. Weed Res. 18:25-31.

BIOLOGICAL CONTROL OF WILD OATS

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Biological control is the deliberate use of living organisms to control a pest. In biological control of weeds two main tactics are being used: the classical or traditional tactic and the augmentative or bioherbicide tactic. The classical biocontrol tactic is based on the philosophy that weeds have escaped their natural enemies when introduced into a new area, and thus have an advantage over the native vegetation. By introducing insects or pathogens from the geographical origin of the weed into such an area, it is expected that they will become established and by self perpetuation reach levels that can cause sufficient stress on the weed to bring its population to a level below economic significance. Several weeds have been successfully controlled by insects (Harris, in press) and pathogens (Cullen, 1978) using the classical biocontrol tactic. The augmentative tactic is a strategy where a pathogen is cultured artificially in large quantities and applied to the weed like a chemical herbicide at a time when the weed is most vulnerable. There are now two bioherbicides licensed in the United States: 'Divine', consisting of a fungus, Phytophthora palmivora, registered by Abbott Laboratories for control of milkweed in citrus groves, and 'Collego', consisting of a fungus, Colletotrichum gloeosporioides f. sp. aeschymene, registered by UpJohn Company for control of northern jointvetch in rice and soybean (Templeton, 1982).

Many pathogens and insects survive the dormant season in diseased plant residue. Therefore, in an undisturbed environment, there is normally sufficient carry-over to start an early build up of the agent the following year to suppress the host plant. On weeds in field crops, however, a pathogen seldom develops into epiphytotic levels, because cultivation practices destroy or remove most of the diseased plants. This leaves too little initial inoculum to start early infections the following season. Consequently, the classical biocontrol tactic, where an agent is introduced and left to develop on its own, works best in undisturbed environments, and is less applicable to weeds in annual field crops. Applying weed pathogens in large quantities as bioherbicides compensates for natural constraints to their epiphytotic development in nature and, therefore, can be effectively used in annual field crops.

CONCERNS AND REQUIREMENTS FOR BIOCONTROL AGENTS

There are objections to the use of plant pathogens in biological control of wild oats (Thurston and Cussans, 1976; Watson and Harris, 1975). A major concern is the lack of specificity in pathogens to prevent attack of the closely related cultivated oats. This is a valid concern, for it would be risky to introduce exotic pathogens for classical biocontrol of wild oats. Likewise it would be risky to use either crown rust (*Puccinia coronata* Cda.) or stem rust (*Puccinia graminis* Pers.) even though they already occur in Canada, because spontaneous mutations from avirulence to virulence occur in both of these rusts (in review by Leonard, 1982). According to Green (1975) virulence changes in *P. graminis* in Canada have occurred in single steps by overcoming one resistance gene at a time. Therefore, even if a rust strain used to control wild oats was avirulent on cultivated oats, there would be a good chance that virulent strains would arise, because the resistance to stem rust in cultivated oats in North America has mainly been governed by one or two resistance genes (Martens *et al.*, 1970).

Because wild oats is a serious problem in annual field crops and closely related to cultivated oats (Sharma and Vanden Born, 1978), augmentative biocontrol is better suited than the classical biocontrol tactic. Pathogens acceptable for biocontrol of wild oats must remain localized within the area of application. Ideally, the pathogens should have lost their viability by the following growing season. If these criteria are met, there should be no damage to cultivated oats in neighboring fields when pathogens are applied to control wild oats. Aside from this, a potential agent for augmentative biocontrol also has to meet the following requirements.

1. It must be sufficiently virulent and aggressive to penetrate and inflict substantial damage to the weed.

2. It must be sufficiently specific not to harm crop plants in which it is to be used.

3. It must be able to be cultured artificially on a large scale and be prepared into a product which can be applied commercially.

4. It must be safe to handle. Only in a very few cases have plant pathogens been associated with human diseases. It is generally regarded safe to work with plant pathogens. However, it is possible that some spores can cause allergies to some sensitive people.

POTENTIALS FOR BIOCONTROL OF WILD OATS

Control of wild oats using plant pathogens is virtually an untouched field. In 'Status of Weed Control with Plant Pathogens' (Templeton, 1982) 51 projects are listed of which two were conducted on wild oats. One described the use of a bacterium, *Pseudomonas syringae* van Hall, and the other a rust *Puccinia coronata* Cda. Early morning inoculations of *Pseudomonas syringae* and *Pseudomonas coronata* under field conditions were successful in infecting wild oats, but neither of these pathogens were capable of reducing the weed growth to any extent (Sands, personal communication, April 6, 1983). *Puccinia coronata* was highly infective on wild oats, but due to danger of attacking cultivated oats, it would be too risky to use it in biocontrol of wild oats.

In spite of the little research being done in biological control of wild oats, several pathogens have been reported in the literature. A thorough review was done by Thurston and Cussans (1976) and, based on 80 papers, they concluded that no study had been done on wild oat diseases directly. All reports were studies of alternative hosts for economically-important pests and diseases of crops. Thus, many of the pathogens reported cause serious diseases of cereals, and they were tested to determine if they could survive on wild oats between susceptible crops. This information is valuable in selecting pathogen species for potential biocontrol of wild oats. Based on this, field surveys for specific pathogens on wild oat plants during the growing season could be done to obtain isolates best adapted to this weed. For example *Colletotrichum graminicolum* (Ces.) Wils. has been reported from cultivated oats (Sandford, 1935) on the prairies, and could possibly occur on wild oats also. It might have potential as a biocontrol agent for wild oats for it is in the same genus as the fungus in the mycoherbicide 'Collego', registered for control of northern jointvetch in the United States (Templeton, 1982).

Fungi associated with seeds of wild oats collected in Europe have been studied (Kiewnick, 1963; 1964) and 52 species of fungi were isolated from the spikelets of wild oat seeds from Germany. A large number of these were found to influence germination and mortality of wild oat seeds in storage as well as in the soil. The five most damaging of these fungi are also known to cause diseases in cereals. Analyzing wild oat seeds from a wide area for potential pathogens for biocontrol would be easier and less time consuming than extensive field surveys. Sources of wild oat seeds are easily obtainable from grain elevators across Canada.

At the Regina Research Station, we are now analyzing wild oat seeds for seed-borne fungi. Several lines with different dormancy and mortality levels under laboratory conditions (Hsiao and Quick, 1983) are included in the tests to look for a correlation between high mortality levels and occurrence of fungi on the seeds. Fifteen different genera of fungi have so far been isolated from surface sterilized seeds, but it is too early to tell whether a correlation of pathogenicity exists.

REFERENCES

Cullen, J. M. 1978. Evaluating the success of the programme for the biological control of *Chondrilla juncea* L., p. 117-121. *In* T. E. Freeman (ed.) *International symposium on biological control* of weeds. Proc., IV. Center Environ. Programs, Univ. Florida. 298 p.

Green, G. J. 1975. Virulence changes in *Puccinia graminis* f. sp. *tritici* in Canada. Can. J. Bot. 53:1377-1386.

Harris, P. (In press). Biological control of weeds in Canada. *In* Biological control programmes against insects and weeds in Canada. Commonwealth Agri. Bur., Farnham Royal, Slough, England.

Hsiao, A. I., and W. A. Quick. 1983. The induction and breakage of seed dormancy in wild oats, p. 163-175. *In* Wild Oat Symposium '83. Can. Plains Res. Center, Regina, SK.

Kiewnick, L. 1963. Untersuchungen uber den einfluss der samenund bodenmikroflora auf die lebensdaur der spelzfruchte des flughafers (*Avena fatua* L.). I. Vorkommen, artzusammensetzund und eigenschaften der mikroorganismon an flughaferfrughten. Weed Res. 3:322-332.

Kiewnick, L. 1964. Untersuchungen uber den einfluss der samenund bodenmikroflora auf die lebensdauer der spelzfruchte des flughafers (*Avena fatua* L.). II. Zum einfluss der mikroflora auf der lebensdauer der samen im boden. Weed Res. 4:31-43.

Leonard, K. J. 1982. The benefits and potential hazards of genetic heterogeneity in plant pathogens, p. 99-112. *In* R. Charudattan and H. L. Walker (ed.) Biological control of weeds with plant pathogens. John Wiley & Sons, New York. 293 p.

Martens, J. W., R. I. H. McKenzie, and G. J. Green. 1970. Gene-for-gene relationship in the *Avena:Puccinia graminis* host-parasite system in Canada. Can. J. Bot. 48:969-975.

Sandford, G. B. 1935. *Colletotrichum graminicolum* (Ces.) Wils. As a parasite of the stem and root tissues of *Avena sativa*. Sci. Agr. 15:370-376.

Sharma, M. P., and W. H. Vanden Born. 1978. The Biology of Canadian Weeds. 27. *Avena fatua* L. Can. J. Bot. 58:141-157.

Templeton, G. E. 1982. Status of weed control with plant pathogens, p. 29-44. In R. Charudattan and H. L. Walker (eds.) Biological control of weeds with plant pathogens. John Wiley & Sons, New York. 293 p.

Thurston, J., and G. W. Cussans. 1976. Plant health and the possibilities of biological control, p. 211-227. In D. P. Jones (ed.) Wild oats in world agriculture. Agri. Res. Counc., London. 296 p.

Watson, A. K., and P. Harris. 1975. Weed control with plant pathogens and nematodes. Can. Agri. 20:26-27.

ENVIRONMENTAL FACTORS INFLUENCING THE RESPONSE OF WILD OATS TO HERBICIDES

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ABSTRACT

This review summarizes results from studies dealing with the influence of soil temperatures and moistures on the response of wild oats to triallate and trifluralin. It also covers the effects of temperature, moisture stress, relative humidity, and rainfall on the efficacy of selected postemergence herbicides, including barban, difenzoquat, flamprop-methyl and diclofop-methyl. It includes pertinent information on the effects of environmental factors on herbicide uptake, transport, and metabolism.

A wild oat herbicide must be tested for several years before it can be registered for use in western Canada. Tests are conducted at various locations to establish that the herbicide will perform consistently at the recommended rate(s) over the broad diversity of weather and soil conditions that occur in each region. Ideally, this ensures that, as long as the chemical is correctly applied, it will provide good wild oat control with no damage to the crop. In western Canada, the commonly used wild oat herbicides usually approach this ideal, but there are times when weather conditions alter plant responses to herbicides, resulting in inadequate weed control, crop injury, or both. Reports that the weather can adversely affect wild oat herbicide performance were summarized in a survey (Chow et al., 1976). Of 160 reported cases of herbicide performance problems, 72% were attributed to abnormal weather conditions.

The effect of weather (environmental) conditions on the efficacy of wild oat herbicides has been inadequately investigated. Undoubtedly, this reflects the many difficulties that are inherent in work of this kind. Of the studies that have been undertaken, the majority have been conducted under artificial environments that are quite unlike actual field conditions. This is not to imply that the work is invalid, but is meant to reiterate the need for discretion when extrapolating the results from controlled environment studies to the more complex field situations.

The effects of environmental (weather) factors on the performance of wild oat herbicides are reviewed here, with particular emphasis on areas of practical relevance to western Canada. The effect of the environment on the response of wild oats to herbicides, including ones not registered in Canada, was reviewed by Holroyd (1976) in the ARC monography, Wild Oats in World Agriculture. Readers are encouraged to refer to this article for additional pertinent information, and to Muzik (1976) for a more general discussion of the influence of environmental factors on herbicide toxicity.

EFFECTS OF SOIL MOISTURE AND TEMPERATURE ON THE ACTIVITY OF SOIL-APPLIED CHEMICALS

The activity of soil-applied herbicides is at least partly dependent on their concentration in the soil and their availability to plants in the zone of active uptake. Consequently, factors that affect either their rate of disappearance, or their adsorption to soil colloids, will influence their field performance. However, the complex interactions between environmental factors, soil persistence, adsorption and desorption, and bioavailability of soil-applied herbicides, will be considered only briefly in this section, since these topics are covered elsewhere in the Proceedings. The principal emphasis will be upon the effects of environmental factors on the response of wild oats to triallate and trifluralin, the two most widely used soil-applied herbicides.

Soil Moisture

Triallate

The efficacy of triallate and its predecessor, diallate, is generally considered to be affected by soil moisture, with the best wild oat control occurring when growing conditions are favorable and the soil is moist. Banting (1967) reported that the minimum gravimetric soil moisture content for diallate activation in a Regina heavy clay was 15% (5% below the permanent wilting point). Similar investigations were conducted by McKercher et al. (1975) by incorporating 1.5 ppmw triallate into three different soils with wilting points ranging from 15 to 30%, and field capacities from 29 to 44%. These experiments indicated that the efficacy of the herbicide was the same regardless of whether the soils were maintained 5% above the wilting points, or 5% below field capacity. The authors concluded that if soil temperature and moisture conditions are conducive to wild oat growth, triallate will perform effectively. The relatively high dosage (1.5 ppmw) of triallate used in the study, compared to actual concentrations detected in field plots (0.4-1.2 ppm) treated at the recommended rate of 1.68 kg/ha (Pchajek, 1982), may have obviated the effect of moisture on the chemical's activity. Furthermore, under field conditions, the top few centimeters of soil into which the chemical is incorporated is often much drier than the underlying soil that sustains wild oat growth.

Studies conducted by Miller and Nalewaja (1976) indicated that the inhibitory effects of triallate vapors on wild oat growth were reduced when the moisture content of the treated soil was decreased below field capacity. Growth reductions from triallate vapors from liquid and granular formulations applied to a soil at field capacity were 43 and 34%, respectively, compared to 8 and 0% from the same formulations applied to air dry soil. In these studies, the triallate-treated soil, and the soil in which the wild oats were growing, were physically separated within a closed system.

From pot experiments where wild oats were sown directly into a sandy loam soil treated with 1.5 ppm triallate (liquid formulation), Hamblin (1977) observed an improvement in wild oat control as the soil moisture content was increased from 8% (air dry) to 20% of field capacity. At field capacity the level of control was less than at 20 or 40% of field capacity. A similar reduction in control was not observed in a silty clay soil as the water content was increased.

In field experiments designed to assess the effect of nitrogen fertilizers on triallate activity, McKercher and McGregor (1980) observed that the effect of NH_4^+ on triallate activity appeared to be related to soil temperature and moisture. Greenhouse studies showed that an enhancement of triallate activity resulting from NH_4^+ additions was most pronounced in soil maintained at the permanent wilting point, or at an intermediate level between the wilting point and field capacity. In soil maintained at field capacity, NH_4^+ triallate was less effective under the drier conditions.

Miller and Nalewaja (1975) compared the activity of postemergence applications of both granular and liquid formulations of triallate to wild oats at the one and three-leaf stages. In these experiments, the wild oats were grown in sub-irrigated pots, with the shoot and root zone separated by a paraffin-petroleum barrier. Wild oat growth was not reduced by either formulation when no moisture was added to the surface of the treated pots. Maximum inhibition of wild oat growth (a 50% reduction in shoot dry weight accumulation after two weeks) occurred with the addition of 10 mm of water to the soil in pots sprayed with the liquid formulation and 20 mm to the soil treated with the granular formulation. None of the postemergence treatments resulted in greater than a 60% reduction in shoot dry weight accumulation after two weeks.

In studies (Molberg et al., 1964), conducted at four locations in western Canada, which compared different methods of soil incorporation of triallate, wheat was most tolerant when the chemical was shallowly incorporated by double harrowing after seeding. In one year, however, at the Brandon location excessive soil moisture during seeding time made accurate seed and chemical placement difficult. There was also a heavy rainfall after the plots were sprayed, and damage to the wheat was observed even with the preemergence incorporated treatments. The authors speculated that the injury was due either to some downward movement of the chemical, or to the late seeding date and the resultant higher soil temperatures, which may have accentuated the chemical's effect on the wheat. Subsequent work by Smith (1970), and Beestman and Deming (1967), indicated that significant downward movement of the chemical is unlikely to occur even after a heavy rain. In studies in which a simulated rainfall of 15.2 cm, applied at 2.5 cm/h, was applied after granular triallate was applied to the surface of a silty clay loam (12% organic matter), more than 95% of the recovered triallate remained localized in the upper 1 cm (Beestman and Deming, 1976).

Trifluralin

Friesen and Bowren (1973), who patterned their experiments after Banting's earlier work with diallate (Banting, 1967), report a reduction in trifluralin's effectiveness in controlling wild oats when the chemical was applied to dry soils. Under growth room conditions, a high level of wild oat control was achieved if the initial moisture equivalent of the trifluralin-treated (0.84 or 1.12 kg/ha) loam soil was 20% or higher. The wilting point and field capacity of the soil were 17 and 28%, respectively. At moisture equivalents of 10 and 15% the trifluralin activity was slightly reduced; whereas at 5% or less, the activity was seriously reduced. The authors concluded that the minimum soil moisture for a high level of trifluralin activity on wild oats growing in this soil type was 10% (7% below the wilting point; 6.5% above being air dry), and speculated that prolonged dry spells after spring application could reduce the chemical's field performance.

More recent studies by Moyer (1979) have confirmed that soil moisture has an effect on trifluralin activity but that the effect of soil moisture on trifluralin efficacy is small compared with the effect of soil organic matter. Moyer (1979) showed that the relationship between soil moisture and the dosage required to reduce wild oat growth by 90% (GR_{90}) was curvilinear over soil moisture contents ranging from 0.25 to 1.2 times field capacity. Higher dosages were required to effectively control wild oats at low and high moisture levels, compared with intermediate moisture levels. On average, the chemical's efficacy was reduced more under the wet conditions than under the dry conditions. The slight reduction in efficacy at low soil moisture contents was consistent with the earlier findings of Friesen and Bowren (1973) and was considered to be a direct reflection of increased herbicide adsorption in the dry soil. In the wet soil, higher dosages required for equi-effective control were considered to be a reflection of reduced herbicide vapor diffusion in the decreased available soil pore space, and increased losses from volatilization and/or anaerobic degradation.

Soil Temperature

Triallate

The inhibitory effect of triallate vapors on wild oat growth was accentuated as soil temperatures were increased (Miller and Nalewaja, 1976). When wild oats were exposed to triallate vapors at 10, 20 and 30°C, growth was inhibited by 34, 44 and 56%, respectively, from the liquid formulation. Possible explanations offered for the increased sensitivity of the wild oats at the higher temperatures were that the herbicide was more available as a result of reduced adsorption in the soil, and that wild oats are inherently more sensitive at higher temperatures.

When triallate was applied as a postemergence application to the soil surface, wild oat control was reduced as the temperature increased from 10 to 30°C (Miller and Nalewaja, 1975). The reduction in activity was greater for the liquid formulation than for the granular formulation. The decline in wild oat control at the higher temperatures was ascribed to an increase in the amount volatilized and a concomitant reduction in the duration of exposure to the herbicide.

Trifluralin

Results from growth chamber experiments (Moyer, 1979) indicated that soil temperature (17, 22 and 27°C) did not significantly affect trifluralin activity. These findings paralleled the observations of Mulder and Nalewaja (1978) who showed that temperature had no effect on trifluralin injury to barley over a range from 10 to 24°C. In contrast, Rahman (1973) demonstrated that both wheat and oats were more severely injured by trifluralin when they were grown in pots under a 16-16°C temperature regime than under a 27-16°C or 32-16°C regime. However, the differences in response between plants grown under different regimes were shown to be statistically significantly ($P = 0.05$) only for wheat seeded 6.3 cm deep, but not for oats or for wheat seeded at a depth of 2.5 cm.

The most comprehensive and practical information on the effect of temperature on wild oat control was reported by Darwent (1980) from work conducted at Beaverlodge. In field studies conducted over three years, wild oat emergence was most effectively reduced by trifluralin in early May when soil temperatures were lowest (7-10.5°C in 1975, 10-15°C in 1976 and 1977). Subsequent experiments conducted in a controlled environment showed that at 4°C trifluralin was much more phytoxic than at 7.5, 10 or 20°C when the germinating seedlings were exposed to the herbicide for the duration of the experiment. At 10 and 20°C, the chemical's phytotoxicity was slightly greater than at 7.5°C. In these experiments, the plants were sampled after the shoots of control plants reached a specific length; hence, those growing at cooler temperatures were exposed to the chemical for a longer time than those growing at the warmer temperatures.

In other experiments conducted as part of the same study in which the germinating seedlings were exposed to trifluralin vapors for periods of up to 72 hours at 7.5 and 20°C, the inhibitory effects on wild oat growth were greater at the higher temperature. Differences in response to the chemical between plants grown at the two temperatures were less pronounced as the period of exposure to the chemical vapors was increased. Darwent (1980) concluded that the increased period of exposure at 7.5°C probably counteracted the increased volatilization of the chemical at 20°C resulting in comparable levels of control. The practical implication of this work is that low soil temperatures do not appear to impair wild oat control with trifluralin and, indeed, may even enhance its effectiveness.

ENVIRONMENTAL EFFECTS ON THE ACTIVITY OF FOLIAR-APPLIED CHEMICALS

Temperature

Warm weather and good growing conditions generally enhance the activity of most postemergence wild oat herbicides; however, some are more phytotoxic when conditions are cool and growth is slow. Unusually warm or cool weather at spraying time may reduce selectivity, resulting in either poor wild oat control or crop injury.

Miller et al. (1978) showed that greenhouse-grown wild oats treated with difenzoquat were less effectively controlled at 10°C than at 20 or 30°C. Wild oat control was the same with 1.12 kg/ha at 10°C, 0.56 kg/ha at 20°C and 0.28 kg/ha at 30°C. Thus, nearly four times as much difenzoquat was required at 10°C than at 30°C for equivalent control.

The differences in wild oats response to difenzoquat at different temperatures can probably be explained by differences in the amount of chemical penetrating the leaves. Sharma et al. (1976) showed that over an eight-hour period, approximately four times as much ^{14}C-labelled difenzoquat penetrated the leaves of wild oats at 20°C than at 10°C, and 1.5 times as much at 30°C than at 20°C. Furthermore, autoradiographic results showed that acropetal transport of difenzoquat was most rapid at 30°C. These results, coupled with the work of Miller et al. (1978), indicate that in cool weather difenzoquat may be less effective, or take longer to act, than in warm weather. Although no efficacy data exists, it seems probable that the phytotoxicity of asulam might also be reduced at low temperatures, based on studies by Sharma et al. (1978), who showed that less than one-seventh as much ^{14}C-labelled asulam penetrated the leaves of wild oats after four hours at 10°C than at 20°C.

Whereas difenzoquat activity was shown to be strongly dependent on air temperatures (Miller et al., 1978), flamprop-methyl activity was unaffected over a similar temperature range (Miller et al., 1979). Averaged over all rates tested, wild oat control with flamprop-methyl was 60, 59 and 63% when plants were maintained from three weeks at 10, 17 and 28°C, respectively. These findings contrast with those of Jeffcoat et al. (1977), who reported that flamprop-methyl activity showed a marked improvement as temperatures were increased. Three weeks after treatment, the height of treated plants maintained at 25°C was approximately 40% of the height of the untreated controls. By contrast, the height of plants maintained at 12°C was 70% of the controls. However, if the temperature was raised from 12 to 25°C one week after treatment, the growth suppression was nearly equivalent to that obtained when the plants were maintained at the higher temperature for the entire post-treatment period. From these results it was concluded that only a prolonged cool period is likely to reduce the chemical's efficacy. Physiological experiments pointed to a reduction in transport of the phytotoxic derivative, flamprop acid, at the lower temperatures as the primary cause for the chemical's reduced effectiveness.

In contrast to these effects, an increase in the phytotoxicity of barban was observed as temperatures decreased (Neidermyer and Nalewaja, 1974). At temperatures near 30°C, barban did not effectively control wild oats in wheat even at rates higher than 1.0 kg/ha. At lower temperatures (16 and 21°C), the chemical was highly selective, effectively controlling wild oats with negligible injury to the crop. When the temperature was dropped to 10°C, injury to the wheat was apparent and the selectivity reduced. The authors concluded that if the weather is unusually cold at the time of spraying, lower rates of barban should be applied, or spraying should be delayed until warmer conditions prevail. Conversely, during prolonged periods of high temperature, higher rates of barban should be applied to control wild oats effectively.

Subsequent studies with barban (Miller et al., 1978) confirmed the previous observations and further established that a period of three days at 10°C following treatment was necessary to cause injury to wheat. Greatest selectivity was observed at 18°C or at alternating day/night temperatures of 18 and 10°C.

Chow (1978) reported that diclofop-methyl applied at 1.1 kg/ha in the greenhouse was more phytotoxic to wild oats at a cool temperature (12°C) than at warmer temperatures (20 and 28°C). In these experiments, the average shoot dry weight reduction for all three temperatures was only about 11%, which seems inordinately low in light of results from other studies (Todd and Stobbe, 1977; Miller and Nalewaja, 1980). A precise definition of the effect of temperature on diclofop-methyl activity requires further experimentation.

In none of the reported studies were the effects of air temperatures less than 10°C investigated. Since temperatures in western Canada can drop to freezing during the spraying season, some additional studies on low temperature effects on herbicide performance are warranted.

Moisture

The influence of moisture stress on the efficacy of difenzoquat and flamprop-methyl was investigated by Miller et al. (1978, 1979) in two separate studies. Unstressed plants were grown in soil that was watered daily to field capacity; the stressed plants were watered only when the wild oats began to wilt. Difenzoquat activity was reduced substantially by a stress period after spraying, but the activity of flamprop-methyl was not. Wild oat control, expressed as a percentage reduction in shoot dry matter three weeks after treatment, was reduced from close to 60% when difenzoquat was applied as 1.12 kg/ha to well-watered controls, to less than 25% when the plants were stressed. These results, together with those of the temperature studies mentioned previously, indicate that, of the two compounds, flamprop-methyl may provide more consistent results under stressful conditions. There is evidence from other studies, however, that an extended period of moisture stress alters the metabolism and transport of flamprop-methyl and its phytotoxic derivative, flamprop acid, in wild oats. This, in turn, was thought to account for a marginal reduction in efficacy (Jeffcoat et al., 1977).

Dortenzio and Norris (1980) reported that the percent reduction in dry weight of wild oats sprayed with 0.6 kg/ha diclofop-methyl declined from 58% when the soil was maintained close to field capacity to less than 16% when the soil was near the wilting point. If the stressed plants were watered two or four days after treatment, there was a partial recovery in activity. The results of radiotracer experiments on uptake and transport of ^{14}C-labelled diclofop-methyl by stressed and unstressed plants did not resolve the basis for the reduced response of the stressed plants, but did indicate that differential absorption was probably not a factor.

Subsequent studies by Akey and Morrison (1983) confirmed that moisture stress reduced the effectiveness of diclofop-methyl. Cumulative differences in spray retention, translocation, and possibly metabolism, were sufficient to explain the reduced activity of the chemical applied to wild oats exposed to moderate soil water deficits. In these experiments, stressed plants and unstressed plants were watered daily so that soil water contents were 10% (-6.5 bars) and 20% (-0.3 bars), respectively. If the stress was maintained for five days after treatment, wild oat control was reduced by 38%. The unstressed plants had 22% greater leaf area and retained 23% more herbicide than stressed plants. Radiotracer experiments showed that although less than 2% of the total applied radioactivity was translocated out of the treated zone of both stressed and unstressed wild oats, significantly greater label accumulated in the combined expanding third leaf, tillers and apex of the unstressed plants 72 hours after application.

Relative Humidity

High relative humidity (90%) and simulated dew after difenzoquat application resulted in better wild oat control than when humidity was low (50%) or there was no dew (Miller et al., 1978). Dew affected the herbicidal activity of difenzoquat less than relative humidity. These results correspond well with earlier reports (Sharma et al., 1976) that humidity influenced difenzoquat penetration into wild oat leaves. After eight hours at 30% R.H., approximately 18% of the applied difenzoquat penetrated the leaves, compared to 32.7% at 90% R.H.. When the plants were kept at low humidity, but the treated spots were re-wetted hourly for the duration of the eight-hour uptake period, about 25% of the amount applied was taken up. These results indicated that the enhanced uptake at high R.H. was only partly attributable to a low rate of drying on the leaf. Increased hydration of the cuticle under high humidity may also have contributed to more rapid penetration.

Sharma et al. (1978) also reported that asulam's toxicity to wild oats was greater at high humidity than at low humidity. Over a 24-hour period, four times as much ^{14}C-asulam was absorbed at high humidity (90%) than at low humidity. When Triton X-100 surfactant was added to the spray solution, the effect of humidity was less pronounced. With the surfactant added, 76% of the amount applied penetrated the leaf at high humidity, compared to 50% at low humidity. Part of the surfactant's effect was to prolong the time the herbicide remained in solution on the leaf surface.

Rainfall

The effect of simulated rain on wild oat herbicides' efficacy has been investigated by Miller et al. (1978, 1979) and O'Sullivan and Vanden Born (1980). Rainfall was simulated either by spraying the treated plants repeatedly with water in a cabinet sprayer (fifteen passes of a nozzle delivering 650 L/ha was determined to be equivalent to 1 mm of rain), or by immersing the sprayed plants in two changes of 3 L of water for 30 seconds each.

Miller et al. (1978, 1979) concluded that rainfall in excess of 0.25 mm within one-half hour after spraying would reduce the efficacy of both difenzoquat and flamprop-methyl. Increasing the water applied to 4 mm resulted in progressively greater reductions in control. Wild oat control from 1.12 kg/ha difenzoquat was reduced from 65% with no rain to 18% with 4 mm of rain. Likewise, control from 0.56 kg/ha flamprop-methyl was reduced from 82% (no rain) to 31% (4 mm rain). A minimum interval of four hours from the time of treatment was required to ensure that rain did not adversely affect the activity of either chemical.

The intervals mentioned above do not coincide well with the observations of O'Sullivan and Vanden Born (1980). They determined that to maintain herbicidal effectiveness the minimum intervals required between spraying and water immersion for different chemicals were as follows: 0-0.5 hours, barban and flamprop-methyl; 1-4 hours, difenzoquat; 4-8 hours, barban-difenzoquat mixture; 8-12 hours, diclofop-methyl. O'Sullivan and Vanden Born (1980) attributed the discrepancy between their findings and those reported previously to differences in experimental method. Further discrepancies exist between the results reported in the scientific literature and information provided by the chemical industry. Manitoba Agriculture recently summarized existing label information, listing the following intervals as being necessary to ensure good control with produces included in the 1983 Guide to Chemical Weed Control: 15 minutes, barban; 1 hour, diclofop-methyl; 2 hours, flamprop-methyl; 6 hours, difenzoquat; and 8 hours, asulam.

Clearly, more and better information is required on how rainfall alters the performance of wild oat herbicides. To do this, better rainfall simulators that can be adjusted to mimic typical rainfall patterns, both in duration and intensity, should be employed. Work of this nature has begun at the Agriculture Canada Station in Lacombe (O'Sullivan, personal communication).

CONCLUDING REMARKS

Unquestionably the level of wild oat control obtained from herbicides is partly dependent on the weather. Under field conditions the extent to which environmental conditions affect a herbicide's performance depends on numerous factors. These include the stage at which the chemical is applied, its physiological mode of action, and the general vigor and competitiveness of the crop. Because of the difficulties in designing experiments that closely approximate field situations, coupled with the fact that two, three, and four-way interactions between independent effects undoubtedly occur and complicate the work, there have been relatively few comprehensive studies on the environment's effects on wild oat herbicide activity. Despite these difficulties, it is important that work of this nature be continued or, better yet, intensified to provide farmers with practical information on the best and most economical wild oat control possible under particular environmental conditions.

REFERENCES

Akey, W. C., and I. N. Morrison. 1983. Effect of moisture stress on wild oat (Avena fatua) response to diclofop. Weed Sci. 31:247-253.

Banting, J. D. 1967. Factors affecting the activity of di-allate and tri-allate. Weed Res. 7:302-315.

Beestman, G. B., and J. M. Deming. 1976. Triallate mobilities in soils. Weed Sci. 24:541-544.

Chow, P. N. P. 1978. Selectivity and site of action in relation to field performance of diclofop. Weed Sci. 26:352-358.

Chow, P. N. P., J. O. Forbes, and H. R. Nelson. 1976. Factors affecting performances of herbicides in Manitoba 1976. Ann. Conf. Manitoba Agronomists (Dec. 14 and 15, 1976.) Proc., 131-139.

Darwent, A. L. 1980. Effects of soil temperature on the phytotoxicity of trifluralin to wild oats. Can. J. Plant Sci. 60:929-938.

Dortenzio, W. A., and R. F. Norris. 1980. The influence of soil moisture on the foliar activity of diclofop. Weed Sci. 28:534-539.

Friesen, H. A., and K. E. Bowren. 1973. Factors affecting the control of wild oats in rapeseed with trifluralin. Can. J. Plant Sci. 53:199-205.

Hamblin, E. F. 1977. The effect of soil temperature and soil moisture on the activity of triallate. M.Sc. Thesis. Univ. Manitoba.

Holroyd, J. 1976. Chemical control, p. 143-210. In D. P. Jones (ed.) Wild Oats in World Agriculture. Agr. Res. Coun., London.

Jeffcoat, B., W. N. Harries, and D. B. Thomas. 1977. Factors favouring the choice of flamprop-methyl, methyl (±)-2-[N-(3-chloro-4-fluorophenyl)benzamido] propionate for the control of Avena species in Wheat. Pestic. Sci. 8:1-12.

McKercher, R. B., R. Ashford, and R. E. Morgan. 1975. Effects of triallate on wild oat grown in a growth chamber. Weed Sci. 23:283-285.

McKercher, R. B., and W. R. McGregor. 1980. Triallate phytotoxicity and nitrogen fertilization. Weed Sci. 28:740-744.

Miller, S. D., and J. D. Nalewaja. 1975. Postemergence application of triallate for wild oat control. Weed Sci. 23:137-141.

Miller, S. D., and J. D. Nalewaja. 1976. Phytotoxicity of triallate vapors to wild oat. Weed Sci. 24:134-136.

Miller, S. D., and J. D. Nalewaja. 1980. Wild oat (Avena fatua) control with fall- and spring-applied triallate. Weed Sci. 28:416-418.

Miller, S. D., and J. D. Nalewaja. 1980. Diclofop (Hoelon) for wild oat and green foxtail control. North Dakota Farm Res. 38:19-22.

Miller, S. D., J. D. Nalewaja, A. Dobrzanski, and J. Pudelko. 1978. Temperature effect on barban phytotoxicity. Weed Sci. 26:132-134.

Miller, S. D., J. D. Nalewaja, and W. A. Olson. 1979. Wild oat control with flufenprop-methyl. Weed Sci. 27:91-95.

Miller, S. D., J. D. Nalewaja, J. Pudelko, and K. A. Adamczewski. 1978. Difenzoquat for wild oat (Avena fatua) control. Weed Sci. 26:571-576.

Molberg, E. S., H. A. Friesen, E. V. McCurdy, and R. D. Dryden. 1964. Placement of di-allate and tri-allate for control of wild oats in wheat. Can. J. Plant Sci. 44:351-358.

Moyer, J. R. 1979. Soil organic matter, moisture and temperature: Effect on wild oats control with trifluralin. Can. J. Plant Sci. 59:763-768.

Mulder, C. E. G., and J. D. Nalewaja. 1978. Temperature effect of phytotoxicity of soil-applied herbicides. Weed Sci. 26:566-570.

Muzik, T. J. 1976. Influence of environmental factors on toxicity to plants, p. 203-247. In L. J. Audus (ed.) Herbicides, Physiology, Biochemistry, Ecology. Vol. 2. Academic Press, London.

Neidermyer, R. W., and J. D. Nalewaja. 1974. Barban selectivity for wild oat in wheat. Weed Sci. 22:476-480.

O'Sullivan, R. A., and W. H. Vanden Born. 1980. The influence of immersion in water on the efficacy of postemergence wild oat herbicides. Can. J. Plant Sci. 60:307-309.

Pchajek, D. A. 1982. Bioactivity and persistence of fall and spring applications of soil-applied herbicides. M.Sc. Thesis. Univ. Manitoba.

Rahman, A. 1973. Effects of temperature and soil type on the phytoxicity of trifluralin. Weed Res. 13:267-272.

Sharma, M. P., W. H. Vanden Born, and D. K. McBeath. 1978. Spray retention, foliar penetration, translocation and selectivity of asulam in wild oats and flax. Weed Res. 18:169-173.

Sharma, M. P., W. H. Vanden Born, H. A. Friesen, and D. K. McBeath. 1976. Penetration, translocation, and metabolism of ^{14}C-difenzoquat in wild oat and barley. Weed Sci. 24:379-384.

Smith, A. E. 1970. Degradation, adsorption and volatility of di-allate and tri-allate in prairie soils. Weed Res. 10:331-339.

Todd, B. G., and E. H. Stobbe. 1977. Selectivity of diclofop-methyl among wheat, barley, wild oat (Avena fatua) and green foxtail (Setaria viridis). Weed Sci. 25:383-385.

COMPATIBILITY OF WILD OAT HERBICIDES

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ABSTRACT

In general, postemergence herbicides for control of wild oats (Avena fatua L.) suffer a reduced phytotoxicity (antagonism) to wild oats when applied as a tank mixture with herbicides for control of broad-leaved weeds. In most cases, the loss of phytotoxicity is on wild oats only with no loss of phytotoxicity of the herbicides for control of broad-leaved weeds. Some of the important exceptions are the following combinations where no antagonisms have been reported: diclofop with benzonitrile herbicides such as bromoxynil or ioxynil or with picolinic acid herbicides such as 3,6-dichloropicolinic acid or picloram; and combinations of difenzoquat with ester formulations of 2,4-D, MCPA, bromoxynil or bromoxynil/MCPA. Most of these mixtures have shown good promise for control of a relatively broad spectrum of weeds in one spray operation. A small loss of wild oat control has been reported when difenzoquat is mixed with chlorsulfuron. A recommendation for use of the latter mixture for control of wild oats and a wide variety of broad-leaved weeds is presented. Generally, antagonism of wild oat control can be overcome by applying the wild oat and broad-leaved weed herbicides a minimum interval of four days apart. Mixtures of reduced rates of barban with reduced rates of difenzoquat or flamprop applied at the two to four-leaf stage of wild oats have been reported to provide as good control of wild oats as the full recommended rates of barban at the two-leaf or difenzoquat or flamprop applied at the four-leaf of wild oats. These mixtures are not currently registered for use, but potentially offer a greater leaf stage of application flexibility over barban, and reduced herbicide costs over difenzoquat or flamprop. In soil applications, triallate mixed with trifluralin provided good control of wild oats and green foxtail. The current status of our knowledge on the compatibility of mixtures of registered herbicides for wild oat control with other herbicides is reviewed in detail. The basis for observed interactions is presented and suggestions for further research are discussed.

INTRODUCTION

Wild oats are virtually ubiquitous in grain fields in western Canada. Most herbicides registered for wild oat control in Canada are relatively species specific in that they control only wild oats. Barban, difenzoquat, flamprop and triallate all fall into this category. Other wild oat herbicides e.g. diclofop and sethoxydim control other grassy weed species in addition to wild oats, but do not control broad-leaved weeds. Only asulam and trifluralin have exhibited limited broad-leaved weed control in addition to control of wild oats. Consequently, it is desirable that herbicides for control of wild oats be compatible with herbicides for control of other weeds, so that either a manufacturer can prepare a package mixture, or a producer can prepare a tank mixture of one or more herbicides. Such mixtures may enable a producer to control a broad spectrum of weeds in a single spray trip over the field, thus avoiding the additional production costs associated with more than one spray operation.

Some wild oat herbicides are relatively leaf stage specific. For example, barban provides best control when applied at the two-leaf stage of the wild oat and difenzoquat or flamprop provide best wild oat control when applied at the five to six-leaf stage. Mixtures of reduced rates of barban with reduced rates of difenzoquat or flamprop, therefore, have the potential to increase the leaf stage of application flexibility over barban alone; or reduce per hectare treatment costs over the recommended rates of the more expensive herbicides, difenzoquat or flamprop.

The purpose of this review is to examine the current status of our knowledge on compatibility of wild oat herbicides (currently registered for use in Canada) mixed together or with herbicides for control of other weeds. No information on mixtures with protectants or other pesticides or adjuvants is included. Only research information on A. fatua in spring cereal and spring oilseed crops is reported. The basis for observed interactions is presented and suggestions for further research are discussed.

ASULAM

Asulam is registered in Canada for control of wild oats and other weeds in flax. While the sodium salt of MCPA did not reduce control of wild oats with asulam (Nalewaja, 1972b), the amine and potassium salts of MCPA with asulam did reduce control of wild oats (Chow, 1977). The potassium salt was less antagonistic than the amine salt. Mixtures of asulam + MCPA, TCA, or bromoxynil/MCPA all antagonized control of wild oats with asulam. The bromoxynil/MCPA mixture was the least antagonistic (Chow, 1977). In other work 4-amino benzoic acid also antagonized the effectiveness of asulam on wild oats (Veerasekaren et al., 1981). In spite of the reported antagonism of wild oat control in mixtures, asulam is registered for use on flax in Canada as a tank mixture with MCPA ester and bromoxynil/MCPA (1:1).

BARBAN

Barban is normally applied at the two-leaf stage of growth of the wild oat and is registered for use on cereal, oilseed and other crops in western Canada.

When barban is applied as a tank mixture with many herbicides for control of broad-leaved weeds, a reduction in control of wild oats over barban alone occurs. Herbicides in a mixture with barban for which information exists on reduced control include: MCPA (Nalewaja, 1973a; O'Sullivan and Vanden Born, 1976); 2,4-D, bromoxynil/MCPA (1:1), and dicamba (O'Sullivan and Vanden Born, 1976); metribuzin and metribuzin plus MCPA (O'Sullivan, 1980); linuron and linuron + MCPA (O'Sullivan, 1981a); propanil and propanil/MCPA (1:0.6) (O'Sullivan, 1981b); picloram/2,4-D (1:16) (O'Sullivan, in press); and 3,6-dichloropicolinic acid (O'Sullivan and Kirkland, in press). No studies have been conducted to determine the nature of the antagonism when barban is tank-mixed with these herbicides for control of wild oats. Also, the antagonism seems to be a one-way antagonism since there is loss of wild oat control, but no loss of control of broad-leaved weeds has been reported.

When MCPA was applied one, two, three and four days after barban, control of wild oats with barban was not reduced (Nalewaja, 1972). In a later study, only partial recovery of barban control of wild oats was obtained with sequential applications of MCPA up to four days after barban (Miller and Nalewaja, 1973).

Two herbicides for control of broad-leaved weeds do not cause a loss of herbicidal activity when tank-mixed with barban. These include: MSMA (Miller et al., 1976) and picloram (O'Sullivan, in press). However, from a practical use standpoint, the potential impact of these mixtures is minimal due to the poor spectrum of broad-leaved weeds controlled. A commercial mixture containing barban/MCPA/mecoprop/dichlorprop (1:0.94:1.9:0.94) was tested by the authors for control of wild oats in western Canada with generally good results, but the mixture was not made commercially available.

A number of studies were conducted to investigate the influence on wild oat control of mixing lower than normally recommended rates of barban with lower than normally recommended rates of other wild oat herbicides. The research centred particularly around mixtures of barban with wild oat herbicides which provided optimum control of following application at later stages of growth (four to six-leaf), for example, difenzoquat and flamprop. These mixtures had the potential to increase the leaf stage of application latitude for barban and, as a result, possibly improve barban's performance. They also had the potential to allow the later applied herbicides to be applied earlier, thereby potentially reducing crop yield losses due to late removal of wild oats; and to reduce producer input costs over the later applied, and considerably more expensive, wild oat herbicides.

Barban and difenzoquat tank-mixed at approximately half the recommended rates of each herbicide alone provided as effective control of wild oats when applied from the two to five-leaf stage of growth as barban applied alone at the recommended rate at the two-leaf stage (Friesen, 1974; O'Sullivan and Vanden Born, 1978). Crop competition was essential to the degree of effectiveness of this mixture (Sharma and Vanden Born, 1981). The interaction between the two herbicides was studied by O'Sullivan and Vanden Born (1978) and was found to be additive.

When barban was tank-mixed with flamprop at reduced rates of both herbicides, control of wild oats with the mixture was excellent following application at the two or four-leaf stage of growth of the wild oat (O'Sullivan and Vanden Born, 1979). There was a synergistic interaction between herbicides. The basis for the synergistic interaction was studied by Sharma et al. (1982). These workers concluded that the synergism occurred as a result of increased absorption of both herbicides following application at the two or four-leaf stage. Translocation or metabolism did not appear to be important factors in the synergism. Competition from the crop was also shown to be an important factor in effectiveness of this mixture for wild oat control (Sharma and Vanden Born, 1981).

The barban plus difenzoquat or flamprop mixtures are not currently registered for use in Canada.

DICLOFOP

Diclofop (refers to methyl ester unless otherwise indicated) is currently registered in Canada for control of wild oats, green foxtail (Setaria viridis L. Beauv.), barnyard grass (Echinochloa crusgalli L. Beauv.), and Persian darnel (Lolium persicum Boiss. and Hohen), in wheat, certain barley cultivars, canola, flax and a variety of other broad-leaved crops. It can be applied from the one to five-leaf stage of the wild oat (Friesen et al., 1976).

A reduction in control of wild oats when phenoxy herbicides such as MCPA or 2,4-D are mixed with diclofop was reported by Behrens et al. (1974), Miller and Nalewaja (1974a), Olson and Nalewaja (1976), and O'Sullivan and Vanden Born (1976). Losses of diclopfop control of wild oats have also been reported with mixtures containing other herbicides such as bromoxynil/MCPA, dicamba, or 2,4-D/dicamba/mecoprop (1:0.36:0.25) (O'Sullivan et al., 1977); dichlorprop or mecoprop (Lutman and Thornton, 1978); metribuzin or metribuzin + MCPA (O'Sullivan, 1980); linuron + MCPA (O'Sullivan, 1981a); propanil or propanil/MCPA (O'Sullivan, 1981b); chlorsulfuron (O'Sullivan and Kirkland, 1983a); and picloram/2,4-D (O'Sullivan, in press).

There has been a considerable amount of research devoted to determining the mechanism of the antagonistic action of phenoxy herbicides to diclofop on wild oats. O'Sullivan et al. (1977) indicated that the antagonism was due to the active ingredients in the phenoxy herbicides rather than to solvent incompatibilities. Todd and Stobbe (1976; 1980) reported that the acid form of 2,4-D was responsible for the antagonism. When tank-mixed, there was no complex formation between 2,4-D amine or diclofop and retention or penetration of diclofop was not affected. Movement of radioactivity to roots and shoot apices following application of ^{14}C-diclofop to wild oat leaves was reduced by 2,4-D amine. De-esterification of diclofop to the acid form was inhibited by 2,4-D. The authors suggest that diclofop moves acropetally in the apoplast while diclofop acid moves basipetally in the symplast to the site of action in the meristematic areas. Accumulation of diclofop in the leaves results in membrane damage and necrosis possibly resulting in a further reduced symplastic transport of the diclofop acid. The basis for the antagonism was a reduced rate of formation, and a reduced rate of movement of diclofop acid to the site of action in the meristematic areas. This resulted in insufficient herbicide in the meristematic areas to kill the wild oat. The plants were able to outgrow the observed leaf injury resulting from the presence of diclofop. In an in vitro study, Hill et al. (1980) reported that 2,4-D did not directly affect the de-esterification of diclofop. They suggested that this reaction in vivo could be a secondary effect resulting from the disruption of transport of diclofop to esteratic sites, which could possibly result from either membrane disruption and/or uncoupling of oxidative phosphorylation due to the presence of 2,4-D. In other work, the antagonistic action of 2,4-D on diclofop activity in wild oats could not be explained in terms of 2,4-D reducing the effects of diclofop on leaf cell membrane permeability (O'Leary et al., 1980).

Absorption of ^{14}C-diclofop was reduced in the presence of MCPA amine (Qureshi and Vanden Born, 1977; 1979a; 1979c). In contrast, Olson and Nalewaja (1982) observed no effects on absorption with similar mixtures. In addition to reduced absorption, Qureshi and Vanden Born (1979a) suggest that the antagonism of wild oat control observed between MCPA amine and diclofop is due to a reduction in the rate of conversion of the methyl ester of diclofop to the acid form and a subsequent acceleration of the conversion of the acid to non-toxic polar conjugates. As a consequence, the pool of diclofop acid in the wild oat plant following application of the mixture is below the level required to kill the plant. In contrast to the results reported by Hill et al. (1980) for 2,4-D, Qureshi and Vanden Born (1979a) found strong inhibition of in vitro conversion of the ester to the acid form of diclofop by MCPA. The reason for this discrepancy is obscure at present. In other work, MCPA antagonism of wild oat control increased as post-treatment temperature increased from 10 to 30°C (Olson and Nalewaja, 1981). Olson and Nalewaja (1982) also reported that MCPA reduced both upward and downward translocation of radioactivity from the point of application on the wild oat leaf which resulted in a greater retention in the treated area. This result differs with the result described earlier for 2,4-D and diclofop in work conducted by Todd and Stobbe (1980).

Salt forms of phenoxy herbicides have been reported to result in more antagonism of wild oat control with diclofop than ester forms (O'Sullivan et al., 1977; Lutman and Thornton, 1978; Qureshi and Vanden Born, 1979a; 1979c). Qureshi and Vanden Born (1979a) reported that mixtures containing MCPA amine and diclofop were unstable and that a breakdown of the emulsions occurred within 30 minutes of mixing. They suggested that this may result in reduced uptake of diclofop. Mixtures with diclofop and MCPA ester were stable. It may be that absorption of less diclofop in the presence of amine versus ester formulations over and above the other interactions described earlier may result in the greater antagonism observed with amines.

A number of different ways of possibly overcoming the antagonism of wild oat control with various diclofop mixtures have been tested. These include adjusting the rates of herbicide application and various timings of sequential applications including the use of double booms to maintain physical separation of the two herbicides in separate spray tanks and, as much as possible, on the leaf surface. Data reported by O'Sullivan et al. (1977) showed that under greenhouse conditions MCPA ester at 0.28 kg/ha caused just as much antagonism of wild oat control as MCPA ester at 0.56 kg/ha. Olson and Nalewaja (1976; 1981) showed that as the rate of diclofop was increased (up to 2.2 kg/ha) in a mixture and the amount of MCPA remained constant, wild oat control was improved. Diclofop at 2.2 kg/ha in a tank mixture with MCPA at 0.15 or 0.3 kg/ha provided as effective wild oat control as diclofop at 1.1 kg/ha. However, crop tolerance was not assessed and the mixtures would be too costly to be of practical significance.

When diclofop and MCPA ester were applied simultaneously, but separately, using a tandem boom arrangement the degree of interference of diclofop absorption depended on the degree of droplet overlap on the leaf surface (Qureshi and Vanden Born, 1979c). Spray volume and direction of spray application were important factors in minimizing the mixing of the spray droplets on the leaves. Wild oat control in the field with this spray method was significantly improved over a tank mixture, but results were not consistent enough to recommend the procedure for practical use. A similar improvement of wild oat control occurred when MCPA and diclofop were applied one to two-minutes apart (Olson and Nalewaja, 1976). MCPA antagonism of wild oat control with diclofop decreased as the time interval between sequential applications increased and antagonism of wild oat control was greater if MCPA was applied before rather than after diclofop (Olson and Nalewaja, 1981). Antagonism of wild oat control was avoided when MCPA was applied more than two days before, or one day after, diclofop. Qureshi and Vanden Born (1979a) reported that most of the ester hydrolysis to the acid of diclofop takes place during the first day after treatment. This is consistent with the results reported above for improved control of wild oats with an application interval of the phenoxy herbicide of one day, or later, following diclofop application. Qureshi and Vanden Born (1979b) further demonstrated that a four-day interval between MCPA and diclofop prevented most of the antagonism. In another study, applications of metribuzin immediately following diclofop under greenhouse conditions did not result in a loss of wild oat control with diclofop (O'Sullivan, 1980).

The antagonism of wild oat control when diclofop is tank-mixed with various herbicides for control of broad-leaved weeds seems to be a one-way antagonism in that there is a loss of wild oat control but no loss of control of broad-leaved weeds. The major broad-leaved weed studied has been Tartary buckwheat and no loss in control has been reported when diclofop is mixed with: 2,4-D or MCPA alone or in various admixtures (O'Sullivan *et al*., 1977); metribuzin (O'Sullivan, 1980); linuron + MCPA (O'Sullivan, 1981a); propanil or propanil/MCPA (O'Sullivan, 1981b); chlorsulfuron (O'Sullivan and Kirkland, in press); or picloram/2,4-D (O'Sullivan, in press).

A number of herbicides for control of broad-leaved weeds do not cause significant antagonism of wild oat control when tank-mixed with diclofop. Some of these appear promising for broad spectrum weed control in cereals but more research is needed in most cases. The herbicides which do not result in loss of wild oat control include: MSMA (Miller *et al*., 1976); bromoxynil (O'Sullivan *et al*., 1977); a commercial mixture of ioxynil/bromoxynil/dichlorprop (Lutman and Thornton, 1978); linuron (O'Sullivan, 1981a); 3,6-dichloropicolinic acid (O'Sullivan and Kirkland, in press); and picloram (O'Sullivan, in press). A commercial mixture of diclofop/bromoxynil is registered for broad spectrum weed control in cereals in western Canada. However, this mixture provides poor control of certain broad-leaved weeds such as some mustard species, compositae species, chickweed (*Stellaria media* L.) and hemp-nettle (*Galeopsis tetrahit* L.). Further research needs to be conducted on improving the spectrum of control of these broad-leaved weeds through evaluation of mixtures of diclofop/bromoxynil with picloram or 3,6-dichloropicolinic acid to improve the compositae, legume, weed spectrum; linuron to improve control of chickweed and hemp-nettle; or four-way mixtures of these herbicides.

It is interesting to note that the structurally related herbicides picloram and 3,6-dichloropicolinic acid which are considered to be auxin-like in their action on sensitive species (Kefford and Caso, 1966) do not cause antagonism of diclofop on wild oats similar to other auxin-like herbicides such as 2,4D, MCPA or dicamba. The reason for the lack of antagonism with picolinic acid type herbicides is unknown at present. Also, Lutman and Thornton (1978) reported that benzonitrile herbicides such as bromoxynil appear to overcome the antagonism of wild oat control experienced with diclofop plus dichlorprop mixtures. However, O'Sullivan et al. (1977) found just as much antagonism of diclofop control of wild oat with a commercial mixture of bromoxynil/MCPA ester as with MCPA ester.

DIFENZOQUAT

Difenzoquat is a postemergence wild oat herbicide normally applied at the three to six-leaf stage of the weed. It is registered for use in Canada on barley and certain wheat cultivars.

In general, difenzoquat is the most compatible of the postemergence wild oat herbicides when tank-mixed with herbicides for control of broad-leaved weeds. Ester formulations of 2,4-D, MCPA, or bromoxynil/MCPA (O'Sullivan and Vanden Born, 1978) did not antagonize control of wild oats when tank-mixed with difenzoquat, whereas amine formulations of 2,4-D and MCPA did reduce control of wild oats. Holroyd and Thornton (1978) also reported antagonism of wild oat control with the potassium salt but not the iso-octyl ester of dichlorprop. Caldicott (1981) showed no loss of wild oat control with esters of various phenoxy herbicides and varying degrees of antagonism with various salt formulations. Miller and Nalewaja (1973b), on the other hand, reported variable results with phenoxy esters and no loss of wild oat control with phenoxy amines.

The mechanism of loss of difenzoquat control of wild oats when mixed with phenoxy amines has not been intensely investigated. However, difenzoquat is a member of the bipyridinium group of herbicides, and losses of activity of paraquat on grass species when mixed with phenoxy amines, but not phenoxy esters, have been reported (O'Sullivan and O'Donovan, 1982; O'Donovan and O'Sullivan, 1982; O'Donovan et al., in press). Losses in the latter studies were attributed to chemical interactions between phenoxy amines and paraquat when the herbicides were together in solution in the spray tank. The lack of antagonism with the esters was attributed in part to the fact that the phenoxy herbicide was dissolved in the oil component of the herbicide formulation, while paraquat was dissolved in the aqueous component. Therefore, the herbicides were not in contact with each other and no interaction occurred. One may speculate that a similar mechanism may account, in part, for the salt/ester antagonism/no antagonism interactions with difenzoquat. Propanil and propanil/MCPA also reduces the phytotoxicity of difenzoquat to wild oats (O'Sullivan, 1981b; Sharma and Vanden Born, 1982). The latter workers observed separation of the components of the mixtures soon after mixing these herbicides and noted a marked inhibition of difenzoquat uptake in the presence of propanil or propanil/MCPA. When the herbicides were applied separately the reduction in uptake depended on the degree of droplet overlap on the leaf surface.

There are a number of other herbicides for which antagonism of difenzoquat control of wild oats has been reported. These include: MSMA (Miller et al., 1976); dicamba and dicamba admixtures (O'Sullivan and Vanden Born, 1977); metribuzin and metribuzin plus MCPA (O'Sullivan, 1980); linuron and linuron plus MCPA (O'Sullivan, 1981a); and picloram/2,4-D (O'Sullivan, in press). A variable loss of wild oat control has been reported for mixtures of chlorsulfuron plus difenzoquat (O'Sullivan and Kirkland, in press). The latter mixture could be used for control of wild oats and a wide variety of broad-leaved weeds with the understanding that some loss in control of wild oats could be expected. The mixture would be most useful where there was a light-to-moderate infestation of wild oats and a slight loss of control would not cause a large reduction in crop yield (O'Sullivan and Kirkland, in press).

In further studies, no loss of phytotoxicity to wild oats was reported when picloram (O'Sullivan, in press) or 3,6-dichloropicolinic acid (O'Sullivan and Kirkland, in press) were mixed with difenzoquat. From these results, it would appear that there is a need for further research with 1) mixtures of difenzoquat and phenoxy esters plus picloram or 3,6-dichloropicolinic acid in order to broaden the spectrum of weeds controlled to include buckwheat, composites and legume species and, 2) mixtures of difenzoquat with chlorsulfuron and picloram or 3,6-dichloropicolinic acid for control of a wide variety of broad-leaved weeds.

Generally, difenzoquat did not adversely affect the activity of the herbicides for control of broad-leaved weeds nor the activity of propanil or propanil/MCPA on green foxtail (see references cited above), indicating that, in most cases, the antagonism was a one-way antagonism. Difenzoquat did appear to reduce control of broad-leaved weeds with MSMA (Miller et al., 1976).

Mixtures of difenzoquat with other herbicides for control of wild oats have been reviewed in the section under barban.

FLAMPROP

The methyl ester of flamprop is currently registered in Canada for control of wild oats in wheat and various forage species. Applications are generally from the three to six-leaf stage of the weed.

Antagonism of wild oat control in tank mixtures of flamprop with 2,4-D, MCPA, dicamba, bromoxynil or bromoxynil/MCPA has been reported (Miller and Nalewaja, 1974b; O'Sullivan and Vanden Born, 1976; 1980). Mixtures containing MCPA or bromoxynil/MCPA were found to be less antagonistic than other phenoxy or benzoic acid mixtures (O'Sullivan and Vanden Born, 1980). Other herbicides were also found to reduce the effectiveness of flamprop to wild oats. These include: 3,6-dichloropicolinic acid (Miller and Nalewaja, 1974b; O'Sullivan and Kirkland, in press); metribuzin (Miller and Nalewaja, 1974b; O'Sullivan, 1980); propanil and propanil/MCPA (O'Sullivan, 1981b); linuron and linuron plus MCPA (O'Sullivan, 1981a); chlorsulfuron (O'Sullivan and Kirkland, in press); and picloram/2,4-D (O'Sullivan, in press). The mechanism by which the antagonism of wild oat control occurs has not been studied extensively. Application of 2,4-D two days before flamprop reduced control of wild oats. However, application at least four days prior or two days after flamprop did not adversely affect control of wild oats (Miller and Nalewaja, 197[illegible]a).

The antagonism of wild oat control reported with mixtures of flamprop and the herbicides for broad-leaved weed control described above was a one-way antagonism in that no loss of control on broad-leaved weeds was observed in any of these studies.

The effect of mixing flamprop with other herbicides on control of wild oats is described earlier under the barban section.

SETHOXYDIM

Sethoxydim is a new postemergence herbicide recently registered in Canada for control of wild oats, green foxtail and volunteer cereals in canola, flax and other broad-leaved crops. It can be applied from the one to five-leaf stage of the weeds.

Dalapon, TCA or MCPA did not antagonize control of wild oats when mixed with sethoxydim at 0.3 kg/ha (Chow, 1983). However, some loss of wild oat control was observed in MCPA mixtures with sethoxydim at 0.1 kg/ha.

TRIALLATE

Triallate is registered in Canada as a soil applied treatment for control of wild oats in cereal, oilseed and other crops. A tank mixture of triallate and trifluralin provided good control of wild oats and green foxtail in wheat (Moyer and Dryden, 1977). This mixture is currently registered for use in wheat and barley. Application of mixtures of AC 206,784 for green foxtail control and triallate for wild oat control did not adversely affect the activity of either herbicide (O'Sullivan *et al*., 1982).

REFERENCES

Behrens, R., M. Elakkad, and L.J. Smith. 1974. Wild oat control in wheat and barley. *N. Cent. Weed Contr. Conf.* Res. Rep. No. 31: 73

Caldicott, J.J.B. 1981. Efficacy of difenzoquat for *Avena fatua* control when used as a tank-mix with broad-leaved weed herbicides in winter wheat and spring barley, p. 313-319. *In* Grass Weeds in Cereals in the United Kingdom Conf.

Chow, P.N.P. 1977. Asulam mixtures for weed control in flax. Weed Res. 17: 55-60.

Chow, P.N.P. 1983. Herbicide mixtures containing BAS 9052 for weed control in flax (*Linum usitatissimum*). Weed Sci. 31: 20-22.

Friesen, H.A. 1974. Barban + AC-84777 (Avenge) mixtures of wild oats control in barley. NCWCC Proc. 29: 48-50.

Friesen, H.A., P.A. O'Sullivan, and W.H. Vanden Born. 1976. HOE 23408, a new selective herbicide for wild oats and green foxtail in wheat and barley. Can. J. Plant Sci. 56: 567-578.

Hill, B.D., B.G. Todd, and E.H. Stobbe. 1980. Effect of 2,4-D on the hydrolysis of diclofop-methyl in wild oat (*Avena fatua*) Weed Sci. 28: 725-729.

Holroyd, J., and M.E. Thornton. 1978. Mixtures of difenzoquat and dichlorprop for the control of *Avena fatua* and broad-leaved weeds in spring barley. Brit. Crop Prot. Conf. Proc. 1978. Weeds 9-13.

Kefford, N.P., and O.H. Caso. 1966. A potent auxin with unique chemical structure-4-amino 3,5,6-trichlorpicolinic acid. Bot. Gaz. 129: 159-163.

Lutman, P.J.W., and M.E. Thornton. 1978. The control of *Avena fatua* and broad-leaved weeds in spring barley with herbicide mixtures containing diclofop-methyl (Hoegrass) and its economic significance. Brit. Crop Prot. Conf. Proc. 1978. Weeds 15-22.

Miller, S.D., and J.D. Nalewaja. 1973a. Influence of additives on wild oat control with barban. NCWCC Res. Rept. 30: 52-53.

Miller, S.D., and J.D. Nalewaja. 1973b. Influence of 2,4-D or MCPA formulations on wild oat control with AC-84777 in wheat and barley. NCWCC Res. Rept. 30: 57-58.

Miller, S.D., and J.D. Nalewaja. 1974a. Control of wild oat and other weeds in flax. NCWCC Res. Rept. 31: 111.

Miller, S.D., and J.D. Nalewaja. 1974b. Influence of broadleaf herbicides on wild oat control with SD-29761. NCWCC Res. Rept. 31: 91.

Miller, S.D., and J.D. Nalewaja. 1974c. Split applications of SD-29761 and 2,4-D for wild oat control. NCWCC Res. Rept. 31: 92.

Miller, S.D., J.D. Nalewaja, and E. Pacholak. 1976. MSMA with other herbicides for wild oat control. NCWCC Proc. 31: 148.

Moyer, J.R., and R.D. Dryden. 1977. Effects of combined applications of triallate or trifluralin with solution nitrogen on wheat, wild oats and green foxtail. Can. J. Plant Sci. 57: 479-484.

Nalewaja, J.D. 1972a. Barban plus nitrogen or MCPA for wild oats control. NCWCC Res. Rept. 29:82.

Nalewaja, J.D. 1972b. Control of wild oats and other weeds in flax. NCWCC Res. Rept. 29: 86-88.

O'Donovan, J.T., and P.A. O'Sullivan. 1982. Amine salts of growth regulator herbicides antagonize paraquat. Weed Sci. 30: 605-608.

O'Donovan, J.T., P.A. O'Sullivan, and C.D. Caldwell. (In press). Basis for antagonism of paraquat phytotoxicity to barley by MCPA dimethylamine. Weed Res.

O'Leary, N.F., J.T. O'Donovan, and G.N. Prendeville. 1980. Effect of diclofop-methyl and 2,4-D alone and in combination on leaf cell membrane permeability of wild oats and barley. Can. J. Plant Sci. 60: 773-775.

Olson, W.A., and J.D. Nalewaja. 1976. HOE-23408 combinations with MCPA and desmedipham. NCWCC Proc. 31: 134-136.

Olson, W.A., and J.D. Nalewaja. 1981. Antagonistic effects of MCPA on wild oat (Avena fatua) control with diclofop. Weed Sci. 29: 566-571.

Olson, W.A., and J.D. Nalewaja. 1982. Effect of MCPA on ^{14}C-diclofop uptake and translocation. Weed Sci. 30: 59-63.

O'Sullivan, P.A. 1980. Control of wild oats and Tartary buckwheat with mixtures of metribuzin and various postemergence wild oat herbicides. Can. J. Plant Sci. 60: 1255-1261.

O'Sullivan, P.A. 1981a. Control of Avena fatua and Fagopyrum tataricum with tank mixtures of linuron or linuron + MCPA and sequential applications of linuron, and postemergence A. fatua herbicides. Weed Res. 21: 211-217.

O'Sullivan, P.A. 1981b. Control of wild oats, green foxtail and Tartary buckwheat with mixtures of propanil or propanil/MCPA and postemergence wild oat herbicides. Can. J. Plant Sci. 61: 383-390.

O'Sullivan, P.A. (In press). Influence of picloram or picloram/2,4-D on control of wild oats (Avena fatua) with four postemergence herbicides. Weed Sci.

O'Sullivan, P.A., P.N.P. Chow, J.H. Hunter, and K.J. Kirkland. 1982. Control of green foxtail in cereals with AC 206,784, alone and in mixtures with triallate for wild oats. Can. J. Plant Sci. 62: 995-1001.

O'Sullivan, P.A., H.A. Friesen, and W.H. Vanden Born. 1977. Influence of herbicides for broad-leaved weeds and adjuvants with dichlorfop-methyl on wild oat control. Can. J. Plant Sci. 57: 117-125.

O'Sullivan, P.A., and K.J. Kirkland. (In press). Chlorsulfuron reduces control of wild oats (Avena fatua) with diclofop difenzoquat and flamprop. Weed sci.

O'Sullivan, P.A., and K.J. Kirkland. (In press). Control of Avena fatua L. and Cirsium arvense (L.) Scop. with mixtures of 3,6-dichloropicolinic acid and four herbicides for control of A. fatua. Weed Res.

O'Sullivan, P.A., and J.T. O'Donovan. 1982. Influence of several herbicides for broad-leaved weed control and Tween 20 on the phytotoxicity of paraquat. Can. J. Plant Sci. 62: 445-452.

O'Sullivan, P.A., and W.H. Vanden Born. 1976. Interactions between wild oat and broadleaf herbicides. WSSA. 25. (Abst.)

O'Sullivan, P.A., and W.H. Vanden Born. 1978. Interaction between difenzoquat and other herbicides for wild oat and broad-leaved weed control in barley. Weed Res. 18: 257-163.

O'Sullivan, P.A., and W.H. Vanden Born. 1979. Interaction between barban and benzoylprop-ethyl, flamprop-methyl or flamprop-isopropyl applied at two growth stages for wild oat control in cereals. Weed Res. 19: 225-259.

O'Sullivan, P.A., and W.H. Vanden Born. 1980. Interaction between benzoylprop-ethyl, flamprop-methyl or flamprop-isopropyl and herbicides used for broad-leaved weed control. Weed Res. 20: 53-57.

Qureshi, F.A., and W.H. Vanden Born. 1979a. Interaction of diclofop-methyl and MCPA on wild oats (Avena fatua). Weed Sci. 27: 202-205.

Qureshi, F.A., and W.H. Vanden Born. 1979b. Split applications and tank mix combinations of diclofop-methyl and MCPA for weed control in barley. Can. J. Plant Sci. 59: 87-92.

Qureshi, F.A., and W.H. Vanden Born. 1979c. Spray droplet distribution and herbicide uptake in sequential applications of diclofop-methyl and MCPA for weed control in barley. Can. J. Plant Sci. 59: 93-98.

Sharma, M.P., F.A. Qureshi, and W.H. Vanden Born. 1982. The basis for synergism between barban and flamprop on wild oat (Avena fatua) Weed sci. 30: 147-152.

Sharma, M.P., and W.H. Vanden Born. 1981. Crop competition and herbicides for wild oat (Avena fatua L.) control in barley and wheat. WSSA 28 (Abst.).

Sharma, M.P., and W.H. Vanden Born. 1982. Interactions between difenzoquat and propanil or propanil/MCPA combinations for wild oat and green foxtail control in barley. Can. J. Plant Sci. 62: 453-459.

Todd, B.G., and E.H. Stobbe. 1976. Basis of the antagonistic effect of 2,4-D on diclofop-methyl toxicity in wild oats. NCWCC/ Proc. 31, 40.

Todd, B.G., and E.H. Stobbe. 1980. The basis of the antagonistic effect of 2,4-D on diclofop-methyl toxicity to wild oat (Avena fatua). Weed Sci. 28: 371-377.

Veerasekaren, P., R.C. Kirkland, and E.D. Parnell. 1981. Studies of the mechanism of action of asulam in plants. Part 1: Antagonistic interaction of asulam and 4-aminobenzoic acid. Pest. Sci. 12: 325-329.

APPLICATION OF LIQUID WILD OAT HERBICIDES

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ABSTRACT

Application requirements for wild oat herbicides specify water volumes of 45 to 110 L/ha for ground equipment and as low as 20 L/ha for aerial application. Nozzle pressures of about 200 kPa are specified for preemergence herbicides and about 300 kPa for postemergence herbicides. These volumes and pressures are easily achieved with modern farm and commercial sprayers. The introduction of the LP spray tips has provided a superior alternative to the standard flat spray tip or the flooding tip, particularly for preemergence applications and for high speed ground applicators. The major weather limitations for postemergence wild oat herbicide application are high wind velocities and the minimum time requirements between application and rainfall.

INTRODUCTION

Farm and commercial sprayers are used to apply a wide variety of herbicides. From the time that 2,4-D was first introduced, until the late sixties when many new herbicides came on the market, there was very little change in the design of farm sprayers. Several of the newer herbicides, including some of the wild oat chemicals have requirements for better uniformity of application and higher water volumes than does 2,4-D. Until major problems began to develop in the field, little or no attention was paid to improving the design of farm sprayers. In the early seventies, through the efforts of extension engineers and herbicide industry representatives, and with the impetus provided by the Wild Oat Action Committee, both farmers and sprayer manufacturers were alerted to the dire need for a complete redesign of farm sprayers. The first manufacturer to develop a suitable sprayer for the new chemicals was Versatile Manufacturing of Winnipeg, and the others followed shortly thereafter. Continuing sprayer developments since the mid-seventies have kept pace with the application requirements of new herbicides so that practically all new Canadian-built farm sprayers are now suitable for the application of wild oat herbicides.

The desire by farmers and commercial applicators to use high speed truck mounted or "floater" sprayers to apply wild oat chemicals has resulted in some additional problems. Maintaining a constant forward speed, a uniform spray pattern, and a constant boom height are much more difficult with a high speed machine. Recent developments in boom mountings and supports and new nozzle designs have produced significant improvements, but continued testing and innovation are still required.

Aerial application of herbicides presents even greater problems in obtaining uniform depositions. Only recently have methods been developed to evaluate deposition patterns, and further refinement is needed before quick and accurate evaluations will be generally available to aerial applicators. The problem of how to improve deposition patterns will then need to be seriously addressed. Methods of reducing spray drift hazards will need to be considered at the same time.

SOIL INCORPORATED HERBICIDES

The soil incorporated wild oat herbicides (triallate, EPTC and trifluralin) have requirements that are easily met by modern farm field sprayers. The specified minimum application volume is 100 L/ha. An application volume of 100 L/ha requires a pump capacity of about 75 L/min for a sprayer with a 20 m boom travelling at 10 km/h. Many of the roller pumps and all of the centrifugal pumps typically used on sprayers have capacities well in excess of 75 L/min. The pressure requirements are also quite low (200 kPa or less) so pump type selection is not critical.

The more demanding requirements for soil incorporated herbicides are in the area of nozzle selection. Since many farmers prefer to attach a sprayer unit to their tillage or incorporation equipment, and since the application often needs to be made on fairly windy days, a low nozzle mounting height and a large droplet size are desired. Uniformity of distribution is not to be sacrificed, however. Flooding types of nozzles have been commonly used because of their wide angles and subsequent low permissible mounting heights. The pattern uniformity is, however, far from ideal in most cases. The introduction of the low pressure tips (LP) by Spraying Systems with both 80° and 110°angles has provided applicators with an improved option. The 110° tip can be mounted at a height of 70% of the nozzle spacing. Spacings of 50 to 100 cm can be used. The larger droplet sizes produced by the LP tips (as compared to equivalent size flooding tips) also reduces the pattern distortion and spray drift when spraying in windy conditions. The distribution patterns from the LP tips are much more uniform than from the flooding tips, and they are less affected by changes in liquid pressure. Because of these advantages the Teejet LP tips are recommended for the application of soil incorporated wild oat herbicides.

POSTEMERGENCE HERBICIDES

Most postemergence wild oat herbicides require a small droplet size and for the spray pattern to be angled 45° ahead to hit the crotch of the wild oat plant. Fairly high nozzle pressures are needed -- diclofop-methyl, asulam and difenzoquat specify 275 kPa, while barban and flamprop-methyl specify a minimum of 300 kPa. These pressures create no problems for roller pumps, but are near the top of the range for centrifugal pumps. Care must be taken to avoid any unnecessary restrictions in the liquid delivery system if a centrifugal pump is being used.

The requirement to angle the spray pattern 45° ahead created problems with some of the earlier sprayers, but all of the modern sprayers are able to make this angle adjustment easily, and are designed to prevent the spray from hitting the frame or wheels when angled ahead. The height adjustment required when angling the boom has also been incorporated into modern sprayer design.

The application volume requirements are generally low, ranging from 45 L/ha for barban to 110 L/ha (minimum) for diclofop-methyl. These volumes are easily achieved with any modern sprayer.

Various nozzle sizes and types are recommended by wild oat herbicide manufacturers. Standard flat fan nozzles are specified by all manufacturers, and flooding tips are suggested as alternates for barban and difenzoquat, particularly at higher wind speeds. Three herbicides -- diclofop-methyl, asulam and sethoxydim -- specifically require that flooding nozzles not be used, due to their poor pattern uniformity. Diclofop-methyl is also not to be applied with Controlled Droplet Applicators (CDA). None of the other wild oat herbicides indicate that CDAs are acceptable either.

HIGH SPEED GROUND APPLICATORS

High speed ground application equipment such as floaters, truck mounted sprayers and Spra-Coupes* have separate recommendations from several herbicide manufacturers. Maximum forward speeds of 18 km/h are specified for diclofop-methyl and difenzoquat, while barban recommends a forward speed of 8 to 13 km/h depending on nozzle type. Nozzle pressure for high speed ground applicators are the same as for farm field sprayers, except for barban and difenzoquat, where pressures of 300 to 450 kPa are recommended when applied with a Spra-Coupe. An assumption is made that the application volumes will be less with a Spra-Coupe than with other sprayers, and the higher pressures are recommended in order to produce a similar number of droplets from the lower spray volumes. The recommended volume for barban is 45 L/ha for all ground applications and if this is achieved with a Spra-Coupe, a pressure of 300 kPa should be adequate. The higher pressures (300 to 450 kPa) are recommended for the Spra-Coupe when difenzoquat is applied in 45 to 50 L/ha. Since difenzoquat is formulated to be applied with 100 L/ha, the lower volume is a compromise, and the increased pressure is an attempt to obtain sufficient coverage by reducing the droplet size. There is a drift caution to be noted with the use of the higher pressures. Only under ideal weather conditions should these high pressures be used, not only to avoid off-target damage but also to prevent the chemical from leaving the field, thereby missing its target. Low temperatures, high relative humidities, and low wind speeds will all help to reduce off-target drift.

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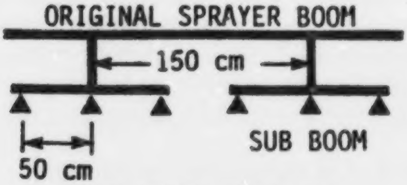
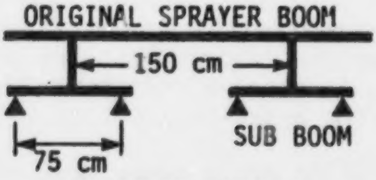
*The use of brand names does not imply endorsement of products by the author; they are used only for identification purposes.

Nozzle type recommendations for high speed ground equipment are not yet well developed by the herbicide manufacturers. Barban manufacturers suggest the use of flooding tips while others strictly specify standard flat spray tips. Good results have been obtained with both types in various conditions, but the better pattern uniformity produced by the flat spray tips would indicate that they should generally be preferred. The use of LP flat spray tips appears to be very promising for high speed ground sprayers since they produce a good pattern over a wide range of nozzle pressures. Field observations by the author confirm the effectiveness of the LP tips when used for applying wild oat herbicides with floaters. LP tips can be used at high pressures (300 kPa or higher) as well as at low pressures. At the higher pressures the droplet sizes are very similar to those produced by the standard flat spray tips. At lower pressures (as low as 100 kPa) they still produce a good pattern and also provide less drift hazard due to larger droplet sizes. Nozzle spacings of 50 to 100 cm can be used for both the standard and LP tips, with a recommended height above target of 90 to 100% of nozzle spacing for the 80° tips and 70% for the 110° tips.

Nozzle mountings on floaters are normally provided at 150 cm spacings for use with flooding nozzles. This is too wide for flat spray tips so an auxiliary boom needs to be provided or, alternately, a small sub-boom assembly can be connected at each outlet as shown below. Various other special boom designs, some of which include end carrier wheels have been built to accommodate the height and spacing requirements of flat spray tips.



FLAT SPRAY TIPS AT
50 cm SPACINGS



FLAT SPRAY TIPS AT
75 cm SPACINGS

Various trials have been made with a short boom mounted ahead of the wheels on floaters to reduce wheel track and dust effects. Observations made by PAMI* and by the author indicate that this frequently results in extremely poor weed control. Mounting nozzles behind the wheels, while sometimes not providing results equal to the area with no wheel tracks, does produce much better results than front mounting.

WEATHER LIMITATIONS

Rainfall immediately following application will result in reduced weed control with postemergence wild oat herbicides. Barban requires 15 minutes between application and rainfall; diclofop-methyl requires 1 hour, difenzoquat requires 6 hours and asulam requires 8 hours. Barban must be applied only to crops with no surface moisture present. Diclofop-methyl should not be applied when the weather is hot and dry.

Maximum specified wind speeds for ground applications are 30 km/h for barban, and 25 km/h for difenzoquat. A general caution on wind speeds is that the further the nozzles are from the crop, the lower the wind speed that can be tolerated. Also, if wild oat herbicides are tank-mixed with other herbicides, the drift hazard is usually increased and a lower maximum wind speed is therefore recommended.

These weather limitations are less severe than those for most other postemergence herbicides, with the exception of the 6 to 8 hour minimum time before a rain.

AIRCRAFT APPLICATION

Five of the postemergence wild oat herbicides have recommendations for aerial application in addition to the ground applications previously discussed. Minimum specified application volumes vary from 20 L/ha for barban, flamprop-methyl and difenzoquat; to 25 to 45 L/ha for barban and 35 L/ha for diclofop-methyl. Minimum nozzle pressures of 300 kPa are specified for diclofop-methyl, barban and flamprop-methyl. The use of Raindrop nozzles is contra-indicated for diclofop-methyl and sethoxydim.

Maximum wind speeds of 13 to 15 km/h are specified for diclofop-methyl, difenzoquat and flamprop-methyl. Barban manufacturers indicate a minimum boom height of 2.5 m for aerial applications.

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*PAMI Report #E1880, 1981, Lethbridge, Alberta.

INCORPORATION OF WILD OAT HERBICIDES

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ABSTRACT

The techniques of incorporating wild oat herbicides using a variety of equipment are discussed. The differing requirements of incorporation depending upon the herbicide, weeds to be controlled, and crop tolerance factors are presented. The effect of various factors on incorporation efficiency, including soil condition, crop residue, timing of the incorporation operation, and kind of equipment are discussed. The proper selection and use of wild oat herbicides, and incorporation techniques influence the economics of wild oat control.

INTRODUCTION

Wild oat control by incorporation of herbicides into the soil is important, even though the number of herbicides available for this purpose is relatively small. Granular and liquid formulations may have little bearing on incorporation procedures, but do determine application techniques.

The purpose of this paper is to discuss factors related to wild oat herbicide use, but not to recommend specific techniques. The decision to use preemergent soil incorporated herbicides for wild oat control must be based upon these and other decisions related to anticipated wild oat population, timeliness, seasonal work load, and factors pertinent to the individual farmer.

PRINCIPLES OF INCORPORATION

Metering and Distributing

These two aspects are important for successful results from soil applied herbicides. A discussion of this topic for wild oat herbicide application has been prepared by Friesen, and therefore will not be presented here. Reports on the performance of equipment used can be obtained from the Prairie Agricultural Machinery Insitute.

Herbicide and Depth of Incorporation

Different herbicides may require a different depth of incorporation for maximum effectiveness. The depth may vary depending upon the prevalent weed to be controlled and the crop to be grown. Trifluralin, for example, is to be incorporated relatively deeply for control of wild oats, but a shallow depth is required for control of green foxtail. In fact, trifluralin applied post-seeding and shallow incorporated will safely control green foxtail in wheat and barley, but if deeply incorporated will injure wheat and barley. A shallow depth may be defined to be less than seed depth (about 5 cm) whereas deep incorporation will be 10 to 15 cm in depth.

Soil Condition

Loose, mellow soils are ideal for mixing the herbicide uniformly to the desired depth. Hard and lumpy soils, and those which are wet and sticky make it difficult to get uniform and proper mixing. Different incorporation procedures are likely required for such soils. The application of volatile herbicides, such as EPTC, onto a wet soil surface may cause rapid losses to the atmosphere.

Dry soil will, in many cases, limit herbicide activity. An incorporation procedure that dries out the soil just before seeding, or even after seeding, can result in poor weed control and poor emergence of the crop. Timing and the method of the incorporation are important where weather conditions will dry out the soil quickly. The herbicide's mode of action and its physical state in the soil determine the activity level in controlling wild oats, but can also influence degree of crop injury where incorrect incorporation procedures have been carried out (Lal and Reed, 1978; 1979).

Referring again to hard lumpy soils: the type of herbicide used, liquid or granular, can determine the procedure used for incorporation. Granules placed on hard lumpy soil before incorporation can fall too deeply between the lumps, whereas liquid is attached to the soil. Therefore, if granules are to be used, it may be necessary to prework the soil to a condition where the granules will be mixed within the desired soil layer. It has been observed that where liquid herbicide is sprayed onto lumpy soil, or soil that remains lumpy after working, weeds survive beneath the lump even though the lump of soil has received the herbicide. Careful assessment of the condition is required. Such lumpy or sticky soils may require several operations to get them into a good condition for proper incorporation. Many operations however, can also further dry out the soil, making it unsuitable for the crop to be planted.

The other extreme is the very loose soft soil, where the recommended procedure for incorporation may leave the soil so fine that it will be subject to both wind and water erosion. Although this condition may be ideal for incorporation, the loss of eroded soil is costly. A minimum of incorporation action should be considered or perhaps avoided if alternate methods of weed control are available. It has been estimated that the loss of 5 cm of topsoil amounts to 700 tonnes/ha at a cost of $2500/ha worth of nutrients according to Lindwall (1980).

Crop Residue

High levels of crop residue or plant growth hinder the effectiveness of liquid formulations of wild oat herbicides. The trash absorbs the liquid which becomes unavailable for weed control. A general recommendation is to reduce crop residue or plant growth in stubble fields so that two-thirds of the field soil surface are visible or black.

Good preparation techniques for stubble application begin with proper straw and chaff spreading when combining. Straw choppers with widespread capabilities are available, or modifications can be made to existing straw choppers. Chaff spreaders are also available to distribute the chaff over a width of 6.096 m or more. Proper spreading eliminates straw or chaff bunches which prevent the herbicides from reaching the soil.

Granular formulations can be applied directly to stubble before tillage providing there are no large bunches of straw or chaff.

Simultaneous, but post-tillage application of wild oat herbicides, either liquid or granular, when seeding or tilling with combined tillage-seeding or tillage equipment is effective. Such incorporation methods can be used on both stubble and summerfallow fields providing the liquid formulation is not sprayed onto stubble or crop residues.

Timing of Incorporation

A fall or spring application decision should be based upon the following:

(1) Effectiveness of the application time
(2) The effect on crop tolerance
(3) Seasonal work load
(4) Potential for soil erosion
(5) The limiting effect on cropping choice if fall applied
(6) Whether spring incorporation has a detrimental effect on the crop seed bed.

Simple, direct answers to these factors are not usually available because accurate predictions of fall rainfall, winter snowfall, and spring climatic and soil conditions are not possible. For example, it is recognized that fall application of triallate can provide more effective weed control, although the margin of crop safety is lower when wheat is seeded into the treated soil. Seeding through the treated layer results in some of the herbicide in too close proximity with the wheat seed (Lal and Reed, 1978; 1979; Ashford, 1975). The practice may result in stand reductions and delayed maturity when combined with dry conditions in winter and early spring, (Sask. Agriculture, Chemical Weed Control, 1983). Fall incorporation increases the potential for soil erosion, while spring incorporation before seeding may dry out the soil, so that crop emergence is poor if rain does not occur soon after seeding.

Fall application can assist in reducing the spring work load, but may result in limiting crop choices the following year. Spring application may reduce the amount of herbicide required, as with liquid trifluralin, which reduces the cost of chemical but adds to the spring work load. Lack of available equipment, tractors, and manpower may mean that fall application and incorporation is appropriate.

EQUIPMENT AND TECHNIQUES OF INCORPORATION

All kinds of tillage equipment may be used to incorporate wild oat soil-applied herbicides. The choice of equipment depends upon:

(1) The herbicide or herbicide mixture
(2) The preferred location of the herbicide in the soil
(3) Soil condition
(4) The availability of implements
(5) Soil erosion potential

Implements fall into broad categories as follows:

(1) Tine implements, including cultivators and harrows
(2) Disc implements
(3) Rotary implements, including rotavators and rotary hoes
(4) Blade and rod weeders

The categories roughly describe the action upon the soil rather than similarities in construction.

The depth of incorporation required for a herbicide determines the type of implement to use for wild oat herbicides. The implement used for deeper placement must be able to penetrate beyond the required depth and provide mixing of the soil. Disc implements are most capable of providing such action since they can invert the soil. The merits and techniques of operation of various machines are described below.

Disc type implements

A variety of disc-type implements are available and include tandem disc harrows, offset disc harrows and one-way disc harrows (discers). These implements are not similar and considerable differences in incorporation performance may be expected. Factors expected to influence performance are:

(1) Diameter, shape and concavity of the discs
(2) Plain or notched discs
(3) Disc angle (usually is adjustable)
(4) Number of gangs.

The maximum depth expected with discs is about one-fourth of the disc diameter. Other disc operating parameters including concavity (radius of curvature), disc sharpness and operating angle, along with the weight on the discs influence the maximum depth. Combinations of diameter, concavity, and depth of tillage result in a critical disc angle. A disc used at an angle below its critical angle will not penetrate as well due to increased vertical force (Harrison and Thivavarnvongs, 1976; Harrison, 1977). Most tandem disc harrows, set at maximum angle, operate below the critical disc angle while offset disc harrows and discers operate above.

Soil movement and inversion increase with increased disc concavity, disc diameter, disc angle and travel speed. Depth of tillage and disc spacing also influence incorporating abilities.

These factors influence how well and deeply a herbicide will be incorporated. Lal and Reed (1976; 1977) reported similar incorporation abilities of a tandem disc and discer with one pass. The discer had one set of discs, adjusted to about 35° and the tandem disc had two sets at 16°; both had the same diameter and operated at the same depth. Generally, disc-type implements will provide deeper incorporation, more soil breakdown, faster and more uniform mixing to the depth of tillage, than most other implements. These should be used where deep incorporation is needed, where the soil is lumpy or sticky and where soil erosion is not considered to be a problem. Two passes are frequently recommended to ensure uniform mixing to the depth of tillage.

Cultivators or tine type implements

Cultivators of all kinds can be used but they tend to give shallower incorporation. Cultivators, like disc machines, vary in ability to incorporate and techniques of operation are important.

Deep tillage, low lift sweeps, wide shank spacing, slow speed and rigid shanks could be expected to result in uneven depth and poor uniformity of incorporation of the herbicide. Shallow tillage, high lift sweeps, narrower shank spacing, high speed and flexible shanks on the other hand can provide uniform, although shallower, incorporation. The higher travel speed at a shallow depth allows soil to be thrown further sideways and upwards to give better mixing. Lumps are also broken up with the erosion potential increased, when operating at high speed.

Harrows

Harrows are useful for shallow incorporation, but the soil needs to be loose otherwise incorporations will be very shallow, (Lal and Reed, 1978). Incorporation is acceptably uniform with two perpendicular operations.

Tine harrows drawn behind cultivators contribute to improved mixing due to the lively action of the tines. As with other equipment, different harrows and their adjustments will produce different results.

Drag harrows on stubble fields may not work very well for incorporation if constantly loaded with trash. Rotary or oscillating harrows are quite effective in trashy conditions because the trash does not accumulate in the harrows.

In all cases, increasing speed of operation will improve the efficiency of the mixing operation and increase the risk of soil erosion.

Rotary type implements

Power rotovators are not normally used for incorporation of wild oat herbicides, although they would be effective. As with other machines, the design of the cutting knives and travel speed determines the ability to incorporate to the required depth (Bode et al., 1979). High power requirements and the increased potential for soil erosion limit their use to smaller areas, such as specialty crops, or areas where erosion is not a problem.

Other rotary-type implements such as rotary hoes or the Stubble Treader*, a variable angled version of a rotary hoe, are satisfactory for shallow incorporation. The soil must be loose from a previous tillage operation for mixing and incorporation to occur.

Wide Blade Machines and Rod Weeders

These machines are not considered satisfactory for incorporation of wild oat herbicides because they cause little soil distur-

*trade name

bance. A rod weeder mixed very little, with a majority of granule herbicide remaining on or very near the surface (Lal and Reed, 1977).

Simultaneous Application and Incorporation

This technique reduces the number of field operations required to apply wild oat herbicides. Both liquid and granular formulations may be applied. Another advantage of the method is that volatile liquid formulations are incorporated immediately with little loss. Disadvantages include the extra equipment to service, particular if combined with a seeding operation, while the seeding operation will be extended because of the dual operation.

The discer-seeder equipped with either a Normand spray attachment or a granular applicator is a satisfactory way of applying triallate. The technique results in a post-seeding application, since the liquid or granules fall into the soil thrown up by the discs, and remains incorporated above the seed. Trifluralin for green foxtail control or a triallate and trifluralin tank-mix for wild oat and green foxtail may be applied in this way. This method requires correct positioning of the spray boom relative to the discs (Lal and Reed, 1977). The location of the falling granules is also important if the proper incorporation location is to be obtained. Spreading devices are usually needed to distribute the granule stream evenly (Lal and Reed, 1978). Although wind is a factor, because triallate granules are readily blown around with a moderate wind, few reports of poor weed control or crop injury are received. The common practice of harrowing and packing after seeding with a discer may minimize the effect of uneven application due to wind or poor application techniques.

The use of other incorporating machines simultaneously with herbicide application does not require any special precautions if the herbicide is applied to the unworked soil ahead of the tillage machine except those relating to trash and lumpy soil. Pre-seeding spring applications of herbicides such as triallate with wheat should be avoided according to recommended practice.

Cost of Incorporation

The cost of incorporating wild oat herbicides is significant and should be considered when selecting a herbicide to control wild oats. Overall costs may be low if incorporation techniques requiring less tillage depth are employed. Post-seeding application of triallate requires harrowing, an operation which will likely be carried out even if the herbicide were not applied. Trifluralin requires a deeper tillage operation adding to the cost in fuel and time.

Triallate may also be applied in combination with dry urea fertilizer in either spring or fall. Where nitrogen fertilizer is required, and cannot be added with the seed, there may be economy in applying triallate in this way. Fertilizer-use efficiency may suffer during dry growing conditions.

Since timeliness is as important to crop production as is the proper seedbed preparation, a more costly incorporation method may be appropriate. Many factors, however, need to be considered before rejecting an incorporation procedure based only on the incorporation cost. These include many of the items mentioned earlier in this paper.

SUMMARY

There are many factors to consider before selecting a method for incorporating wild oat herbicides. Those of importance include the soil condition, crops to be grown, equipment available, seasonal work load, soil erosion potential, crop residues and costs.

The choice of herbicide or herbicide mixture will determine the method of incorporation most suitable for the weeds and crop. The timing of application and incorporation can be important to avoid herbicide losses and crop injury with some herbicides. Liquid or granular formulations do not require different incorporation techniques, although granular material eliminates the need for hauling water, an advantage during the seeding operation.

Close attention to the herbicide label recommendations concerning application and incorporation techniques is required to ensure best results. A careful assessment of soil and field conditions is needed to avoid drying out the soil at seeding time, and to avoid unduly increasing the potential for soil erosion. Although many machines will serve to incorporate herbicides, some types are preferred for particular herbicides. The recommended incorporation techniques, if followed carefully, after assessing and making allowance for field conditions, will allow the herbicide to be effective unless conditions are extreme.

REFERENCES

Ashford, T. 1975. Triallate granule spacing effect on oats. Weed Sci. 23:470-472.

Bode, L. E., K. H. Reed, M. R. Gebhardt, and C. L. Day. 1969. An evaluation of herbicide incorporation equipment. Res. Bull. 946, Columbia Agric. Exp. Sta., Mo.

Crop Protection Section, Plant Industry Branch. 1983. Chemical Weed Control in Cereal, Oilseed, Pulse and Forage Crops. Sask. Agr.

Harrison, H. P. 1977. Soil Reacting Forces for Discs from Field Measurements. Transactions of the ASAE, 20(5):836-838.

Harrison, H. P., and T. Thivavarnvongs. 1976. Soil Reacting Forces from Laboratory Measurements with Discs, Can. Agr. Eng. 18(1):49-53.

Lal, R., and W. B. Reed. 1976. Report on engineering study of wild oats control 1975-76. (Unpublished research report). Dep. Agr. Eng., Univ. Sask., Saskatoon, SK.

Lal, R., and W. B. Reed. 1977. Report on engineering study of equipment for wild oats control. (Unpublished research report). Div. Supp. Serv. Contract No. OSW70-0006.

Lal, R., and W. B. Reed. 1977. Studies of machines for incorporation of pre-emergent herbicides. Can. Agr. Eng. 19(1):6-11.

Lal, R., and W. B. Reed. 1978. Report on engineering study of equipment for wild oats control. (Unpublished research report). Div. Supp. Serv. Contract No. OSZ77-00029.

Lal, R., and W. B. Reed. 1979. Report on engineering study of equipment for wild oats control. (Unpublished research report). Div. Supp. Serv. Contract No. OSZ78-00051.

Lindwall, C. W. 1980. Minimum Tillage: An Overview Paper No. 80-308. Can. Soc. Agr. Eng. 60th Ann. AIC Conf.

PERSISTENCE OF WILD OAT HERBICIDES

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ABSTRACT

The persistence and fate of the herbicides asulam, diclofop-methyl, EPTC, flamprop-methyl, sethoxydim, triallate and trifluralin in Canadian soils is reviewed and discussed.

Whether directed at the soil or growing crop, herbicides come into contact with the former. The soil persistence of a herbicide is complex, being dependent upon chemical structure, physical properties (especially those of water solubility and volatility), soil adsorptive properties, temperature and moisture conditions in the field soils after application, soil composition, soil microbial content, and probably other and unknown factors.

Once present in the soil, chemical and biochemical processes can degrade the herbicide. Breakdown is dependent upon chemical structure of the organic molecule, with some configurations being relatively easy to degrade by microbiological processes, while other structures are markedly resistant to microbial decomposition. In the soil environment, biological breakdown is favored by mild and moist conditions and under cold and/or dry soil regimes degradation can be minimal.

Herbicide losses from treated soils can also occur as a result of leaching into the subsoil, and by volatility losses. Both of these processes are governed to some extent by the adsorption of the chemicals to soil colloids, and especially to the soil organic matter. Therefore, the greater the adsorption of a herbicide to the organic component, the less the losses by both leaching and volatility.

Since soil conditions vary from site to site and from year to year, persistence data are specific to a particular location and time. For this reason laboratory persistence studies conducted under fixed conditions of temperature and moisture can give only an indication of what might be expected to occur under field conditions.

In recent years, twelve wild oat herbicides have been registered in Canada, of which only two (barban and difenzoquat) have not had their persistence studied under Canadian conditions.

Field persistence data have been reported for benzoylprop-ethyl (Smith, 1979a), diallate (Smith and Hayden, 1976), and dinitramine (Jensen and Kimball, 1980; Pritchard and Stobbe, 1980; Smith, 1975; Smith and Hayden, 1976, 1982a), but these herbicides are no longer registered for use in Canada, and so will not be discussed.

In this presentation, the fate, in Canadian soils, of the herbicides asulam, diclofop-methyl, flamprop-methyl, EPTC, sethoxydim, triallate, and trifluralin, will be reviewed.

ASULAM

Asulam is used in postemergence treatments for the control of wild oats and other weeds in flax. The herbicide is a non-volatile moderately strong organic acid, which exists in most neutral and alkaline solutions as the water-soluble ionised form. Disappearance of asulam from treated soils is due to a combination of leaching and biological degradation.

The presistence of asulam has been extensively studied at different temperature and moisture regimes in Regina heavy clay (Smith and Walker, 1977). Breakdown was rapid in clay at temperatures in the range 20-35°C and at moisture levels above 50% of field capacity, when the half-life values were approximately seven days. At lower soil temperatures and/or moisture levels breakdown was slower. In soil at 20% of field capacity losses were negligible over a 56-day period.

Under Saskatchewan field conditions using small plots sited on heavy clay, sandy loam, and silty clay soils, no asulam residues were recovered five months after May treatments, equivalent to 2.5 kg/ha, for three consecutive years (Hayden and Smith, 1980a).

Since asulam is not adsorbed to soil colloids (Smith and Walker, 1977), it is capable of extensive leaching. It has been reported (Smith and Walker, 1977) that asulam can be leached to the 5-10 cm soil depths under field conditions. However, even at these depths, the herbicide appears to undergo biological degradation so that no residues are carried over to the next crop year.

DICLOFOP-METHYL

Diclofop-methyl is used in postemergence treatments for the control of wild oats and other grassy weeds in a variety of crops. The herbicide is non-volatile, and loss of the chemical in treated soils results from biological breakdown.

On soils with moisture levels in excess of their wilting points, diclofop-methyl undergoes a rapid hydrolysis to the acid which then slowly degrades (Smith, 1977). Under laboratory conditions in heavy clay, sandy loam, and silty clay at 20°C and at 85% of field capacity, the half-life of the acid was approximately 28 days (Smith, 1977).

In Saskatchewan, the persistence of diclofop-methyl at rates of 1.5 kg/ha, has been investigated in small plots of heavy clay, sandy loam, and silty clay for two consecutive years. By October no ester remained in any of the top soils, while the acid recovered was less than 8% of the original ester applications (Smith, 1979a). The herbicide was not leached below 5 cm under field conditions.

4-(2,4-Dichlorophenoxy)phenol has been isolated from field soils as a minor metabolite of the herbicide (Smith, 1979b).

EPTC

EPTC is registered as a soil incorporated treatment for the control of wild oats and other weeds in sunflowers. The herbicide is very volatile having a vapor pressure of 34 x 10^{-3} mm at 25°C. The chemical is lost from the soil both by volatilization and by biological degradation.

The persistence of EPTC has been studied (Smith and Hayden, 1982b) at three sites in Saskatchewan under field conditions for three successive years, using small field plots. Although the herbicide was incorporated into the top 10 cm of the plots during May, no detectable residues were recovered after 22 weeks from the 5-10 or 10-15 cm soil depths of any treated plots. On clay loam soil a residual trace (less than 10% of that applied) of EPTC was noted in the top 5 cm of treated plots after 22 weeks for two of the three years. Carry-over in the top soil of heavy clay applications was observed only one of the treatment years (about 5% of that applied), while in sandy loam soil, complete loss had occurred after 22 weeks during all three years (Smith and Hayden, 1982b).

FLAMPROP-METHYL

Flamprop-methyl is used in postemergence treatments for the control of wild oats in spring wheat. The chemical is nonvolatile and loss of the herbicide from treated soils is a result of biological degradation.

In Saskatchewan, the persistence of flamprop-methyl, at a rate of 1 kg/ha, has been investigated in small field plots situated on heavy clay, sandy loam, and silty clay soils for two successive years (Smith, 1979a). In field soils, flamprop-methyl is hydrolyzed to the free acid which then undergoes degradation. By the middle of October, following May treatments, approximately 20% of the applied herbicide remained as the ester, and between 6 and 16% as the acid in the top soil of silty clay plots. By the end of the growing season approximately 12% of the initial flamprop-methyl remained in the ester form in the top 5 cm soil levels of the heavy clay plots and about 8% as the flamprop acid. In the sandy loam plots, between 2 and 12% ester remained in October in the top soil, while a further 5% of the applied herbicide was in the acid form (Smith, 1979a).

Under field conditions, no residues of either the ester or acid forms were detected at soil depths greater than 5 cm (Smith, 1979a).

SETHOXYDIM

Sethoxydim is used as a postemergence treatment for the control of annual and perennial grasses (including wild oats) in oil seed crops and sugarbeets. The herbicide is non-volatile, and loss from treated soils is probably due to a combination of chemical and biochemical degradation.

The persistence of sethoxydim has been investigated in soils at 20°C and at 85% of field capacity (Smith and Hsiao, in press). Degradation was rapid, with half-life values in the clay loam and sandy loam being 12 days. In the heavy clay, the half-life of sethoxydim was 26 days. After 28 days, there was negligible breakdown of the herbicide in any of the three air-dried soils at 20°C and at 15% of field capacity moisture.

The persistence of sethoxydim at a rate of 1 kg/ha has been studied under field conditions in Saskatchewan using small plots (Smith and Hsiao, in press). For three consecutive years, no residues of the herbicide were detected in the clay loam, heavy clay, or sandy loam field plots at either the 0-5 or 5-10 cm depths in September following May applications (Smith and Hsiao, in press).

TRIALLATE

Triallate is used as a soil incorporated treatment for the control of wild oats in a variety of crops. The herbicide is very volatile having a vapor pressure of 1.2×10^{-4} mm at 25°C. Triallate is lost from the soil by both volatilization and biological degradation. Volatilization is considerably greater from moist soils than from dry. It is also known that loss of chemical from the soil is greater from surface incorporations than from deep, and that persistence is greater in organic soils than in light textured soils.

Persistence studies with triallate have been reported only for Saskatchewan soils (Smith, 1971, 1975, 1979c; Smith and Hayden, 1976, 1982a, 1982c). Thus, following May soil incorporations to small plots, between 3 and 64% of applied triallate can remain in the soil at the end of the growing season. In the case of fall incorporations, the amounts of triallate recovered from small plots the following May varied from 20 to 75% of that applied (Smith, 1975; Smith and Hayden, 1982a).

The above studies were all conducted using emulsifiable concentrate formulations. It has been reported (Smith and Hayden, 1981) that the carry-over of granular formulations of triallate in Regina heavy clay plots is approximately twice that of emulsifiable concentrate applications. This difference in persistence has been attributed to a greater loss of triallate from the more volatile emulsifiable form (Smith and Hayden, 1981).

No leaching of triallate occurs under field conditions.

TRIFLURALIN

Trifluralin is used as a soil incorporated treatment for the control of wild oats and other weeds in a variety of crops. The herbicide is very volatile having a vapor pressure of 1.99×10^{-4} mm at 29.5°C. The herbicide is lost from the soil by volatilization and biological degradation. As with triallate, trifluralin undergoes greater volatilization from moist soils than dry, and losses are greater from light textured soils than from organic soils. Persistence is also dependent upon depth of chemical incorporation.

The persistence of trifluralin has been investigated in the soils of three provinces. In Manitoban soils, the carry-over 50 weeks after May incorporations ranged from 17 to 26% (Pritchard and Stobbe, 1980). In Saskatchewan soils, between 8 and 53% of the applied trifluralin could be recovered from soil plots in October following spring treatments (Smith, 1972, 1975, 1979c; Hayden and Smith, 1980b; Smith and Hayden, 1976, 1982c). In Nova Scotian soils, 44 to 74% of May incorporations remained in the soil after 28 weeks (Jensen and Kimball, 1980). For fall applications, amounts of trifluralin remaining in the soil in spring were about 60% of that applied in Nova Scotian soils (Jensen and Kimball, 1980) and between 17 and 71% in Saskatchewan (Smith, 1975; Smith and Hayden, 1982a). All these studies involved emulsifiable concentrate formulations.

No leaching of trifluralin occurs under field conditions.

REFERENCES

Hayden, B.J., and A.E. Smith. 1980a. Persistence of herbicides in three Saskatchewan soils. Can. J. Plant Sci. 60: 311-313.

Hayden, B.J., and A.E. Smith. 1980b. Comparison of the persistence of ethalfluralin and trifluralin in Saskatchewan field soils. Bull. Environ. Contam. & Toxicol. 25: 508-511.

Jensen, K.I.N., and E.R. Kimball. 1980. Persistence of dinitramine and trifluralin in Nova Scotia, Canada. Bull. Environ. Contam. & Toxicol. 24: 238-243.

Pritchard, M.K., and E.H. Stobbe. 1980. Persistence and phytotoxicity of dinitroaniline herbicides in Manitoban soils. Can. J. Plant Sci. 60: 5-11.

Smith, A.E. 1971. Disappearance of triallate from field soils. Weed Sci. 19: 536-537.

Smith, A.E. 1972. Persistence of trifluralin in small field plots as analyzed by a rapid gas chromatographic method. J. Agric. Fd. Chem. 20: 829-831.

Smith, A.E. 1975. Field persistence studies with herbicides in prairie soils, p. 266-270. In Coulston and Korte, Environmental quality and safety. Supplement. vol. 3. Thieme, Stuttgart.

Smith, A.E. 1977. Degradation of the herbicide dichlorfop-methyl in prairie soils. J. Agric. Fd. Chem. 25: 893-898.

Smith, A.E. 1979a. On the extraction of free and bound carboxylic acid residues from field soils treated with the herbicides benzoylprop-ethyl, diclofop-methyl, and flamprop-methyl. J. Agric. Fd. Chem. 27: 428-432.

Smith, A.E. 1979b. Transformation of (^{14}C)diclofop-methyl in small field plots. J. Agric. Fd. Chem. 27: 1145-1148.

Smith, A.E. 1979c. Soil persistence experiments with (^{14}C)2,4-D in herbicidal mixtures, and field persistence studies with triallate and trifluralin both singly and combined. Weed Res. 19: 165-170.

Smith, A.E., and B.J. Hayden. 1976. Field persistence studies with eight herbicides commonly used in Saskatchewan. Can. J. Plant Sci. 56: 569-571.

Smith, A.E., and B.J. Hayden. 1981. On the long-term persistence of 2,4-D and triallate in Saskatchewan soils. EWRS Symp. on the Theory and Practice of the Use of Soil Applied Herbicides Proc. 156-162.

Smith, A.E., and B.J. Hayden. 1982a. Carry-over of dinitramine, triallate and trifluralin to the following spring in soils treated at different times during the fall. Bull. Environ. Contam. & Toxicol. 29: 483-486.

Smith, A.E., and B.J. Hayden, 1982b. Comparison of the persistence of EPTC, metribuzin and propanil in Saskatchewan field soils. Bull. Environ. Contam. & Toxicol. 29: 243-247.

Smith, A.E., and B.J. Hayden. 1982c. Field persistence studies with triallate and trifluralin both singly and in combination with chloramben. Bull. Environ. Contam. & Toxicol. 29: 240-242.

Smith, A.E., and A.I. Hsiao. (In press). Persistence studies with the herbicide sethoxydim in prairie soils. Weed Res.

Smith, A.E., and A. Walker. 1977. A qualitative study of asulam persistence in soil. Pestic Sci. 8: 449-456.

TRANSPORT OF WILD OAT HERBICIDES IN THE ENVIRONMENT

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ABSTRACT

Wild oat herbicides represent a wide spectrum of compounds which includes cationic, anionic, as well as neutral molecules. Thus, enormous variability in their behaviour in the environment can be expected. The two ionic herbicides, asulam and difenzoquat, are highly soluble in water and have practically no vapor pressure. These two should be non-volatile under field conditons. However, asulam is anionic, has little or no adsorptive potential, and is thus subject to mobility in soil, whereas difenzoquat is cationic, chemically adsorbed to soils, and is immobile when ionized. The other four post-emergence herbicides, barban, diclofop-methyl, flamprop-methyl, and sethoxydim, have low water solubilities and are reported to show little or no mobility in soils, which presumably reflects their high adsorptive potential. Two of these, diclofop and sethoxydim, also have low vapor pressures and diclofop has no vapor activity under field conditions. The vapor activity of the other two can be expected to be low or negligible. Of the three soil-applied, preemergence herbicides, EPTC is moderately soluble in water and has the highest vapor pressure and is thus likely to be mobile both in water as well as vapor, when the soil is moist. The other two, triallate and trifluralin, have low water solubilities and relatively high vapor pressures and both are strongly but reversibly adsorbed on soil colloids. Their mobility in soil can be expected to be minimal; however, significant vapor losses of both can be expected under moist soil conditions. Airborne residues of triallate and trifluralin can be detected throughout the growing season in areas where these two herbicides are extensively used.

INTRODUCTION

Losses of herbicides to the environment can occur via several different pathways. It can occur during application, where a portion of the herbicide may not land on the target, or after application as losses from the target. Application losses, commonly known as 'drift,' may vary from as low as less than 1% to over 50%, depending on operational, equipment, environmental, and other factors during spraying (Maybank et al., 1978). Post application losses of herbicides from the target areas can occur in moving waters, such as under leaching, surface runoff, tail waters in irrigated soils, etc. (Grover, 1976), or by direct escape of the herbicide vapor to the atmosphere (Taylor, 1978). The magnitude of post-application losses may vary from being negligible to over 25%, again depending on factors such as type of target, nature of chemical, mode of transport, etc. This review will enumerate some of the major factors that determine post-application losses of herbicides and present available quantitative data on losses of wild oat herbicides to the environment after application under a variety of situations relevant to the prairies.

FACTORS AFFECTING OFF-TARGET TRANSPORT OF HERBICIDES FROM TREATED FIELDS

The movement of herbicides in the environment involves several different processes as well as compartments (Fig. 1). Herbicides can move within, as well as between, compartments; for example, in the soil compartment chemicals may move by diffusion or mass transport processes. The soil particles themselves may move in the air

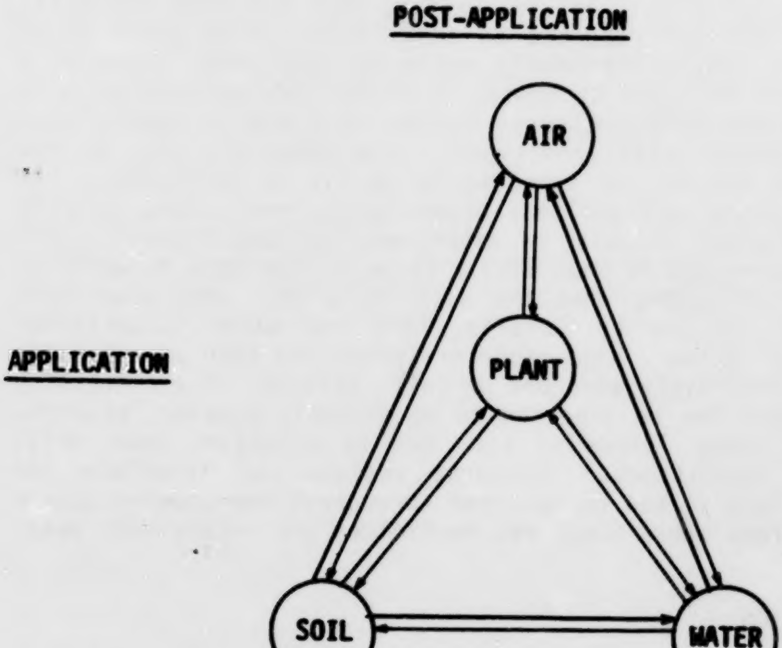
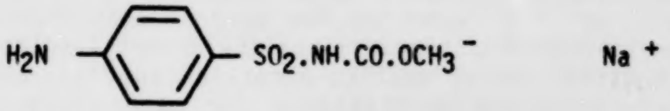


Fig. 1 Pathways of herbicide transport in the environment

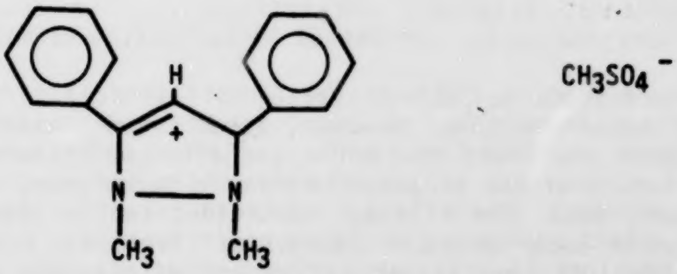
or water compartments, carrying herbicides in the adsorbed state with them. Atmospheric turbulence conditions may remove and transport herbicide vapor from the soil to the air compartment. Once a herbicide is in the water, whether in the solution form or in the adsorbed state on the sediments, its further transport would be defined by the appropriate hydrological parameters. When a herbicide finds its way into the air, its rate and direction of movement would be determined by the appropriate meteorological conditions. However, our present concern is the transport of herbicides in the treated fields and within the various interfaces in their immediate vicinity, which involves interfaces such as soil:air, water:soil, water:air, etc. Some of the factors that determine movements within these interfaces, such as water solubility, ionization constant, soil adsorption estimates, and vapor pressure, are listed in Table 1.

All but one of the seven non-ionic and ester-type wild oat herbicides have very low water solubilities, ranging from <1 µg/ml for trifluralin to 35 µg/ml for flamprop-methyl; water solubility of the seventh, EPTC, being 370 µg/ml (Table 1). Asulam and difenzoquat, the two ionic herbicides, are marketed as Na and methyl sulfate salts, respectively, and these two are much more soluble in water.

The behaviour of some herbicides depends on the extent to which they exist as the neutral or charged species. The relative proportion of these two chemical species is a function of their dissociation constant, pK, and is dependent on the pH of the environment. The pK_a of asulam is 4.82 whereas that of difenzoquat is not known (Table 1). Although both of these herbicides are ionic, they have opposite charges on dissociation, i.e. asulam is anionic and difenzoquat is cationic.



ASULAM



DIFENZOQUAT

The pK_a's of the two acid herbicides, diclofop and flamprop, which are marketed as methyl esters, are also not known.

Table 1 Water solubility, ionization constant (pK_a), adsorption estimate (K_d) and vapor pressure of wild oat herbicides

Herbicide	Solubility	pK_a	K_d*	Vapor pressure
	(μg/ml)			(kPa)
asulam	5,000 (20/25)	4.82	( )**	'negligible'[1]
difenzoquat	76.5% (23)	( )	( )	'negligible'[2]
barban	11 (25)	--	( )	( )
diclofop methyl	3 (22)	( )	( )	3.0×10^{-8}(20)[3]
flamprop methyl	(35) (15/25)	( )	( )	( )
sethoxydim	24/ (25)	--	( )	1.3×10^{-8}( )[4]
EPTC	370 (20)	--	( )	4.5×10^{-3}(25)[5]
triallate	4 (25)	--	23-140[6]	2.5×10^{-5}(25)[7]
trifluralin	1 (27)	--	96-315[6] 224-1503[9]	3.2×10^{-5}(25)[8]

* μg herbicide adsorbed/g of soil at soln conc of 1 μg/ml

** ( ) refers to missing data

[1] Ball et al., 1965; [2] Anon., 1979; [3] Anon., 1978; [4] McAvoy, 1982; [5] Anon., 1979; [6] Grover et al., 1979; [7] Grover et al., 1978; [8] Spencer & Cliath, 1974; [9] Moyer, 1979

The soil:water partition or distribution coefficient, K_d, is an index or estimate of the herbicide distribution in the two phases that are in equilibrium with one another and is usually a constant. Thus the K_d values or adsorption estimates provide information on the relative adsorption/desorption potential of several herbicides on a soil or of a herbicide for several soil types. These estimates determine the relative availability of soil-applied herbicides for weed control, their leaching potential in different soil types, and their potential availability for vapor losses, degradation, etc. The relative K_d estimates for the two major soil-applied herbicides, triallate and trifluralin, for several Saskatchewan and Manitoba soils, are listed in Table 1.

Potential evaporation or volatilization of herbicides is a function of their vapor pressure. However, actual vapor losses of these chemicals under the field conditions are affected by several factors, such as nature of the target, atmospheric turbulence, soil moisture conditions, etc. The wild oat herbicides can be readily classified into three vapor pressure categories (Table 1). Category I contains the ionic herbicides asulam and difenzoquat with 'negligible' or 'no' vapor pressure. Category II encompasses the postemergent herbicides sethoxydim and diclofop, with low or intermediate vapor pressures. The soil-applied herbicides triallate, trifluralin and EPTC, with relatively high vapor pressures, can be included in Category III. The vapor pressure data for barban and flamprop-methyl are not available.

POST-APPLICATION LOSSES UNDER FIELD CONDITIONS

Losses via Leaching

A knowledge of the potential movement of herbicides in the target soils is important in the understanding of (a) the performance of soil-applied herbicides against weeds and safety to the crops and (b) the risk of leaching through the soil to the ground water and its possible contamination. Some of the major factors that determine the leaching potential of herbicides are: (1) herbicide solubility, (2) adsorption/desorption estimates for various soil types, and (3) amount, timing and frequency of precipitation.

Based on the properties of the wild oat herbicides listed in Table 1, and in some cases persistence studies in the field (Smith, 1982), the relative leaching potential of these herbicides can be expected to be in the following increasing order:

. No leaching	- cationic herbicide - chemical adsorption	difenzoquat
. Little/no leaching	- strongly adsorbed, but by weak physical forces - low solubility	barban diclofop-methyl flamprop-methyl triallate trifluralin
. Some leaching	- moderate adsorption - medium solubility	EPTC
. Significant leaching	- anionic herbicides - little or no adsorption - high solubility	asulam

Losses in Spring Runoff (Snowmelt)

It is well established that 90% or more of surface runoff in southern Saskatchewan can be attributed to spring snowmelt (Nicholaichuk, 1967). Thus fall-applied herbicides, such as triallate and trifluralin, would be expected to be lost in spring runoff following snowmelt. Preliminary assessment of the results from a long-term field experiment suggests that such losses may be very minimal, being of the order of 0.1% or less, depending on the volume of runoff (Table 2).

Table 2 Loss of triallate* in spring runoff from snowmelt (from Nicholaichuk & Grover, 1983)

Year	Treatment	No. of samples	Runoff volume	Concentration	Amount of loss	% of applied
		(no.)	(mm)	(μg/liter)	(g/ha)	(%)**
1980	fallow	3	7.3	1.58	0.12	<0.01
1981	fallow	2	2.6	6.77	0.18	0.01
1982	fallow	5	23.6	4.20	0.99	0.07
1983	fallow					

* application rate = 1400 g/ha
** 0.01% loss = 0.14 g/ha

Losses in Tailwaters Following Irrigation

In irrigated areas, herbicides are generally applied directly to the field, followed by one or more irrigation. More recently, application of herbicides, such as EPTC, via irrigation water, 'herbigation,' is also being suggested. In either case, a portion of these herbicides is lost in tailwaters, during and immediately following irrigation.

In a study carried out at Outlook, Saskatchewan, maximum concentrations of triallate, trifluralin, and diclofop, in the tailwaters following first irrigation were 1.8, 0.7, and 2.3 g/liter, respectively (Table 3). However, the concentration of soil-applied herbicides in the drain canal, which carried all of the waste water from this irrigation basin, were below the detection limit of 0.1 μg/liter. Presumably, these two herbicides were partitioned into the sediments or, more likely, dissipated from the waste canal as vapor. Diclofop, however, was found in the waste canal during the spraying season, with highest level being 6.1 μg/liter (Table 3).

Table 3 Maximum concentrations of wild oat herbicides in the initial flush of the tailwater after first irrigation of treated fields and in waste canal downstream of treated area at Outlook, Saskatchewan (from Cessna and Grover, 1982)

Herbicide	Maximum amounts found in tailwater	Maximum amounts found in drain canal
	(μg/liter)	
diclofop	2.3	6.1
triallate	1.8	< 0.1
trifluralin	0.7	< 0.1

In a more extensive study on the losses of EPTC, following a 'herbigation' treatment, 7% of the chemical was removed in the tailwaters (Table 4). However, over 70% of EPTC was lost to the atmosphere as vapor within two days after application. These results confirm that herbicides with 'significant' vapor pressure are most likely to be dissipated as vapor, especially under wet soil conditions.

Table 4 Amounts of EPTC in runoff and volatilized from water and wet soil, during and after a flood irrigation application to alfalfa (from Cliath et al., 1980)

EPTC	kg/ha	% of total applied
- Applied in irrigation water (ave. 2.17 ppm)	3.04	100.0
- Runoff in tailwater (ave. 1.70 ppm)	0.21	7.0
- Volatilized from water*	0.86	28.4
- Volatilized from wet soil**	1.38	45.2
- Total volatilized	2.24	73.6
- Total lost	2.45	80.6

*Volatilized between 1445 and 2025 h on day of application (day 1)
**Volatilized between 2025 on day of application and 1845 h on day 3

Volatilization Losses

Recent studies on the measurement of airborne residues of herbicides and, more recently, on the actual volatilization rates of herbicides from treated fields have emphasized volatilization process as a major pathway for the dissipation of herbicides in the environment. It can be assumed safely that a portion of each herbicide that has some vapor activity, enters the atmosphere where it may remain as a highly mobile residue for varying lengths of time. The fate of these mobile airborne residues is, however, only partly understood.

Airborne Residues

Phytotoxic effects of vapor drift from 2,4-D esters treated fields have been recognized since 1945 (Staten, 1946). However, the magnitude of atmospheric contamination from herbicide vapor losses became apparent only after the direct measurement of airborne residues, initially of 2,4-D derivatives (Farwell et al., 1976; Grover et al., 1976), and more recently from soil-applied and incorporated wild oat herbicides (Grover et al., 1981, 1983a).

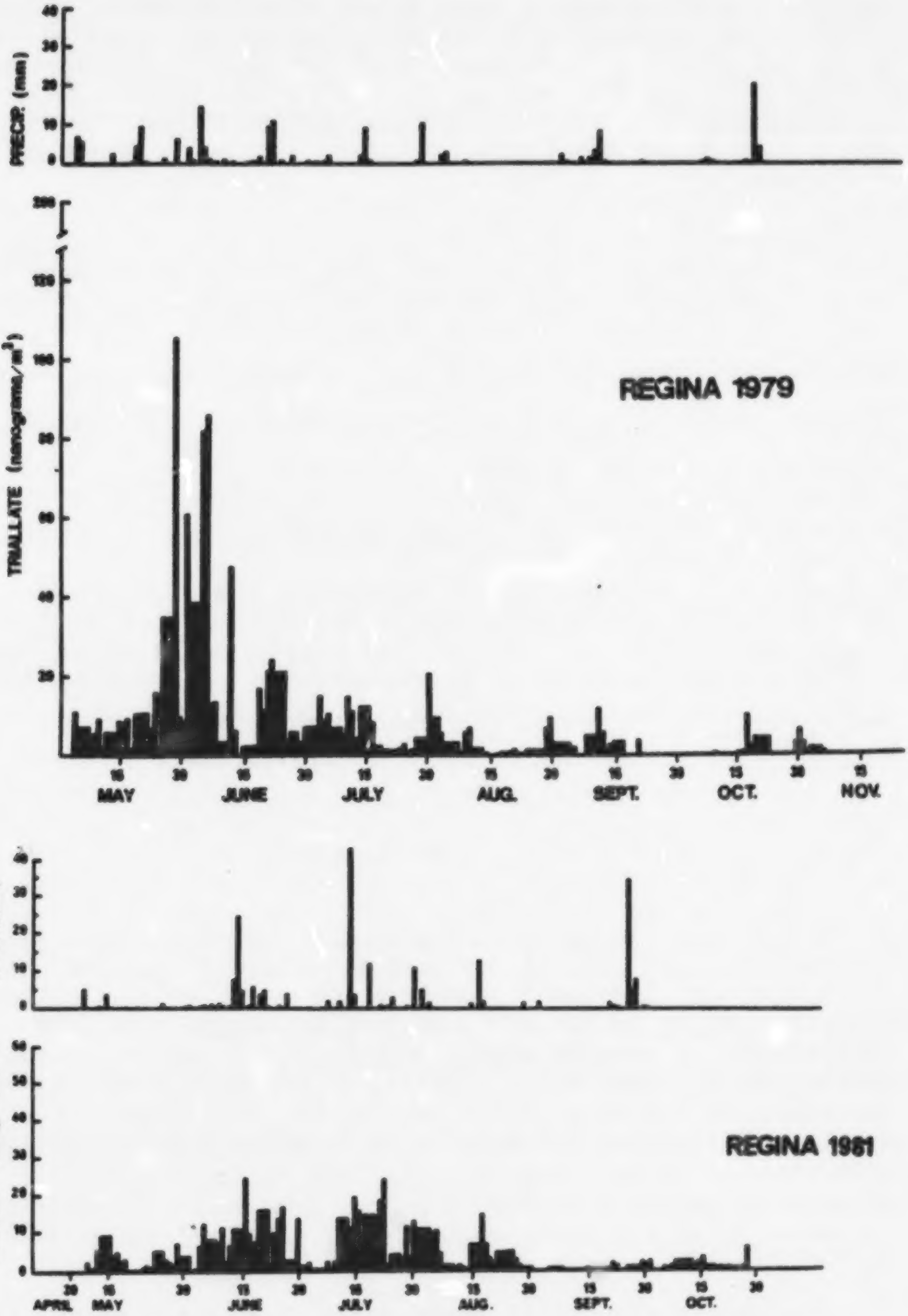


Fig. 2 Airborne residues of triallate during the growing season at Regina, Saskatchewan following a 'wet' (1979) vs. a 'dry' (1981) application period in the spring (from Grover et al., 1981, 1983a).

Airborne residues of triallate were reported throughout the growing season at several locations in Saskatchewan (Grover et al., 1981, 1983a). Maximum concentrations of triallate were found during the peak spraying season in May only when the soil moisture conditions were relatively 'wet' (Fig. 2). In 'dry' springs, the airborne residues were higher in the summer following rainfall events than during the application period, again confirming the role of water in the release of herbicide vapor from the treated soils. Airborne residues of trifluralin were found primarily in the rapeseed growing areas (Fig. 3) (Grover et al., 1983a). Maximum concentration of 200 ng/m^3 of triallate were found during May 1978 at Regina, whereas that of trifluralin were 62 ng/m^3 in June 1982 at Melfort. The airborne residues of these two herbicides usually decreased to 10 ng/m^3 or less in the summer, especially during dry soil moisture conditions or following freezing of the soil in the fall.

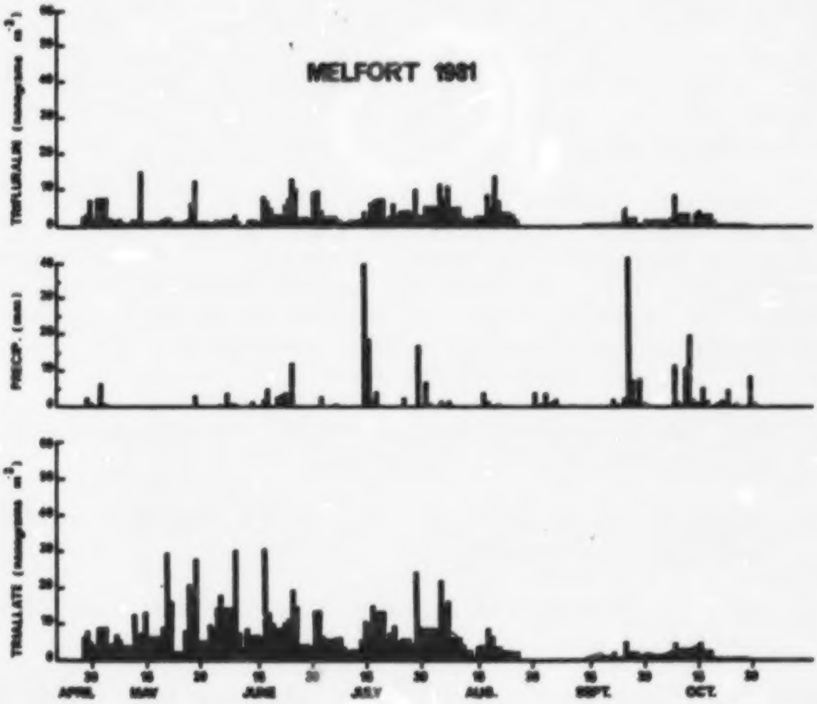


Fig. 3 Airborne residues of triallate and trifluralin during the 1981 growing season at Melfort, Saskatchewan. (from Grover et al., 1983a).

Field Volatilization Studies

More recently, attempts have been made to determine quantitatively vapor losses of both postemergence and soil-applied herbicides (Harper et al., 1976; White et al., 1977; Cliath et al., 1980; Glotfelty, 1981; Grover et al., 1983b,c,d). A major portion of postemergence herbicides is deposited on the crop/weed canopy. The magnitude of vapor losses from the crop canopies is governed by two separate processes. There is the initial evaporation of the herbicide at the crop:air interface. This evaporative process is controlled by the surface area of the deposit, vapor pressure of the herbicide, and the temperature in the vicinity of the leaf surfaces, provided the vapor pressure is not affected by chemical adsorption reactions at the leaf surfaces or there is rapid adsorption of the herbicide into the leaves themselves. The subsequent removal of the herbicide from the plant:air boundary layers is a function of the atmospheric turbulence conditions. the rate of vapor losses of herbicides that have significant vapor pressure, such as 2,4-D iso-octyl ester, is initially rapid and decreases as the leaf surface residues are depleted (Grover et al., 1983b). The complete absence of vapor flux of diclofop-methyl under similar field conditions, on the other hand, can be attributed to its low vapor pressure, coupled presumably by its rapid adsorption, hydrolysis, and absorption at the leaf surfaces (Grover et al., 1983c; Shimabukuro et al., 1979).

The dominant factor affecting the volatilization of preemergence soil-applied herbicides, whether surface applied or incorporated, is their soil adsorption potential which reduces their vapor pressure. Thus for soil-applied herbicides, the rate of vapor losses is controlled by four successive processes, with adsorption/desorption potential as a major determinant for the first three of the four processes. These are:

(a) rate of desorption for the soil (adsorption/desorption potential),

(b) movement to the soil surface, if incorporated (diffusion and mass flow potential,

(c) rate of evaporation at the soil surface (vaporization potential) and,

(d) rate of movement away from the surface (atmospheric turbulence potential).

As shown in Table 2, soil-applied herbicides, such as triallate and trifluralin, are strongly adsorbed to the soil (Grover et al., 1979; Moyer, 1979). Their vapor losses from dry soil are virtually nil (Smith, 1970; Spencer and Cliath, 1974; Harper et al., 1976). However, both of these herbicides are readily desorbed from the soil in the presence of water and are then available for transport to the soil surface by diffusion and mass flow and eventual evaporation at the wet soil surfaces (Grover, 1974; Spencer and Cliath, 1974; Jury et al., 1980). A summary of field experiments on wild oats herbicide volatilization losses are presented in Table 5.

Table 5 Summary of agronomic and soil conditions, location, and volatilization losses of selected wild oat herbicides.

Herbicide	Crop/soil conditions	Type of application	Location	Fraction (%) volatilization in stated period	Reference
diclofop methyl	wheat rainfall 11 mm events 3	postemergence	Regina, SK	'nil' in 7 days	Grover et al. (1983c)
EPTC	alfalfa soil wet	surface-applied 'herbigation'	Brawley, CA	74% in 2 days	Cliath et al. (1980)
trifluralin	bare soil moist	surface-applied	Beltsville, MD	90% in 2/3 days	Glotfelty (1981)
trifluralin	soybean rainfall 165 mm events 3	preemergence incorporated (2.5 cm depth)	Athens, GA	22% in 120 days	White et al. (1977)
trifluralin	wheat rainfall__mm events	preemergence incorporated (5 cm depth)	Regina, SK	__% in ___ days	Grover et al. (1983d)
triallate	as above	as above	Regina, SK	__% in ___ days	Grover et al. (1983d)

REFERENCES

Anonymous. 1978. Technical Information, Hoe-Grass. Agric. Dept., Hoechst Canada Inc. p. 8.

Anonymous. 1979. Herbicide Handbook. Weed Sci. Soc. Amer., 4th ed., Champaign, Illinois.

Ball, R. W. E., H. F. Cottrell, and B. J. Heywood. 1965. Benzenesulphonylcarbamate herbicides, p. 55-56. In 2nd Symp. on New Herbicides. European Weed Res. Council.

Cessna, A. J., and R. Grover. 1982. Preliminary studies on herbicide contamination of irrigation return flow water at Outlook, Saskatchewan. In Wastes and Prairie Water Quality. Water Studies Inst. Symp. No. 8:7.

Cliath, M. M., W. F. Spencer, W. J. Farmer, T. D. Shoup, and R. Grover. 1980. Volatilization of S-ethyl N, N-dipropylthiocarbamate from water and wet soil during and after flood irrigation of alfalfa field. J. Agric. Food Chem. 28:610-613.

Farwell, S. O., E. Robinson, W. J. Powell, and D. F. Adams. 1976. Survey of airborne 2,4-D in south-central Washington. APCA J. 26:224-230.

Glotfelty, D. E. 1981. Atmospheric dispersion of pesticides from treated fields. Ph.D. Dissertation. Univ. Maryland.

Grover, R. 1974. Adsorption and desorption of trifluralin, triallate, and diallate by various adsorbents. Weed Sci. 22:405-408.

Grover, R. 1976. Herbicide use and water quality in irrigated watersheds. International Comm. on Water Qual., Garrison Dam Project, p. 321-351, Appendix A, Water Quality Report.

Grover, R., J. D. Banting, and P. Morse. 1979. Adsorption and bioactivity of diallate, triallate, and trifluralin. Weed Res. 19:363-369.

Grover, R., L. A. Kerr, K. Wallace, K. Yoshida, and J. Maybank. Residues of 2,4-D in air samples from Saskatchewan. 1966-75. J. Environ. Sci. Health, B11(4):331-347.

Grover, R., L. A. Kerr, and S. U. Khan. 1981. Multidetector gas chromatographic determination and confirmation of airborne triallate residues in Saskatchewan. J. Agric. Food Chem. 29:1082-1084.

Grover, R., L. A. Kerr, K. Bowren, and S. U. Khan. 1983a. Airborne residues of triallate and trifluralin in Saskatchewan (unpublished data).

Grover, R., S. R. Shewchuk, A. J. Cessna, A. E. Smith, and J. H. Hunter. 1983b. Fate of 2,4-D iso-octyl ester after application to wheat (unpublished data).

Grover, R., S. R. Shewchuk, A. J. Cessna, A. E. Smith, and J. H. Hunter. 1983c. Fate of diclofop after application to wheat (unpublished data).

Grover, R., S. R. Shewchuk, A. E. Smith, A. J. Cessna, and J. H. Hunter. 1983d. Fate of triallate and trifluralin after application to wheat (unpublished data).

Grover, R., W. F. Spencer, W. J. Farmer, and T. D. Shoup. 1978. Triallate vapor pressure and volatilization from glass surfaces. Weed Sci. 26:505-508.

Harper, L. A., A. W. White, R. R. Bruce, A. W. Thomas, and R. A. Leonard. 1976. Soil and microclimate effects on trifluralin volatilization. J. Environ. Qual. 5:236-242.

Jury, W. A., R. Grover, W. F. Spencer, and W. J. Farmer. 1980. Modeling vapor losses of soil-incorporated triallate. Soil Sci. Soc. Amer. J. 44:445-450.

Maybank, J., K. Yoshida, and R. Grover. 1978. Spray drift from agricultural pesticide applications. APCA J. 28:1009-1014.

McAvoy, W. J. 1982. Today's Herbicide: Past. Weeds Today 13(2):7-8.

Moyer, J. R. 1979. Soil organic matter, moisture, and temperature: Effect on wild oats control with trifluralin. Can. J. Plant Sci. 59:763-768.

Nicholaichuk, W. 1967. Comparative watershed studies in southern Saskatchewan. ASAE Trans. 1(4):502-504.

Nicholaichuk, W., and R. Grover. 1983. Loss of fall-applied triallate in spring runoff from a small agricultural watershed (unpublished data).

Shimabukuro, R. H., W. C. Welsh, and R. A. Hoerauf. 1979. Metabolism and selectivity of diclofop-methyl in wild oat and wheat. J. Agr. Fd. Chem. 27:615-623.

Smith, A. E. 1970. Degradation, adsorption, and volatility of diallate and triallate in prairie soils. Weed Res. 10:331-339.

Smith, A. E. 1982. Herbicides and the soil environment in Canada. Can. J. Soil Sci. 62:433-460.

Spencer, W. F., and M. M. Cliath. 1974. Factors affecting vapor loss of trifluralin from soil. J. Agric. Food Chem. 22:987-991.

Staten, G. 1946. Contamination of cotton fields by 2,4-D or hormone type weed sprays. J. Amer. Soc. Agron. 38, 536-544.

Taylor, A. W. 1978. Post-application volatilization of pesticides under field conditions. APCA J. 28:922-927.

White, A. W. Jr., L. A. Harper, R. A. Leonard, and J. W. Turnbull. 1977. Trifluralin volatilization losses from a soybean field. J. Environ. Qual. 6:105-110.

ADSORPTION AND BIOAVAILABILITY OF WILD OAT HERBICIDES AND ASSOCIATED EFFECTS IN EFFICACY AND SOIL FERTILITY

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ABSTRACT

Wild oat herbicides are adsorbed primarily by the organic matter fraction of the soil. Smaller amounts of herbicides are adsorbed by the clay fraction, but in soils that are extremely dry, wild oat herbicides may form bonds with exchangeable cations on clays. These bonds form at soil moisture levels somewhat less than permanent wilting point. There is evidence that the soil close to the surface does become extremely dry and that most of the herbicide in this layer is adsorbed to the soil. In controlled environment experiments, there is a high degree of correlation between soil organic matter content and the amount of herbicide required to control wild oat. However, in the field, the degree of correlation is not as great because environmental factors such as moisture and temperature cause variability in wild oat control.

INTRODUCTION

Several of the most frequently used wild oat herbicides are applied to soil. These herbicides include triallate and trifluralin in the major field crops such as wheat, barley, rapeseed, and flax, and herbicides such as atrazine, EPTC, or EPTC plus a protectant, which are not normally considered as wild oat herbicides but do control wild oats plus other weeds in special crops.

It is generally assumed that the fraction of soil-applied herbicides adsorbed to soil is unavailable to weeds. Mass flow of water to plant roots takes the herbicide that is in the solution to the root where it can be adsorbed by the plant; or, herbicides can diffuse from soil solution into the emerging plant shoot (Walker, 1980; Schmidt and Pestemer, 1980). Triallate and trifluralin may be taken up by the plant from the vapor phase (Banting, 1967; Swann and Behrens, 1972). The amount of herbicide in the vapor phase is related to the amount in solution by Henry's law, which essentially states that the vapor pressure of a solute above a solution should be directly proportional to the concentration in the solution. Because of the large adsorption capacity of most soils for triallate and trifluralin, both solution and vapor concentrations are low and movement throughout the soil, or to plants, is greatly restricted (Beestman and Deming, 1976; Harper et al., 1976).

FACTORS AFFECTING ADSORPTION OF SOIL-APPLIED HERBICIDES

Soil Components

Silt, sand, and non-expanding clays have very small capacities for adsorbing herbicides but clay, particularly smectites or montmorillonites, and organic matter adsorb large quantities of herbicides (Moyer, 1971; Walker, 1980). Soil organic matter is usually the most important adsorbant for herbicides (Bailey and White, 1964; Grover, 1974). The correlation between the amount of trifluralin adsorbed to soil at a solution concentration of 1 g/ml and the organic matter content was 0.88 for 11 Manitoba soils with organic matter contents from 3.9 to 19.5% and clay contents from 16 to 75% (Moyer, 1979). Similarly, Grover et al. (1979) concluded that organic matter was the most significant factor affecting the adsorption of diallate, triallate, and trifluralin in five Saskatchewan soils.

Soil Moisture

There is little information about the effect of moisture levels between field capacity and the permanent wilting point on the adsorption of herbicides to soil. Soil water extracted with a pressure membrane apparatus had slightly lower triallate concentrations (Table 1) at higher than at lower applied pressures for all NH_4^+-nitrogen concentrations (Moyer et al., 1981).

Table 1 Concentration of triallate (μg/ml) in water extracted from Souris sandy loam soil

NH_4-N (μg/g)	Pressure (kPa)			
	50	100	500	1500*
0	0.18	0.17	0.16	0.15
350	0.20	0.17	0.13	0.13
1400	0.19	0.17	0.13	0.13

*At the permanent wilting point kPa = 1500.

Over a similar moisture range, atrazine concentrations in soil extracts did not differ significantly (Scott and Lutz, 1971).

At moisture levels below the permanent wilting point there are numerous reports that several herbicides are tightly bound to soil. Smith (1970) showed that there was little volatization of triallate from air-dry soil during 28 days at 50°C. Trifluralin vapor losses were minimal from dry field soils during high daytime temperatures (Harper et al., 1976). Therefore, under extremely dry conditions several herbicides have been almost completely removed from the soil solution and air by adsorption to soil particles. It is not clear in the literature, however, how low the soil moisture level must be before almost complete adsorption occurs. Harper et al. (1976) suggest that the rate of trifluralin vapor loss from field soil varies with moisture content when soil particles have from one to three monolayers of water molecules. For their soil, a monolayer was equivalent to about 2% moisture. Rough calculations indicate 2% moisture is equivalent to one monolayer on the Lethbridge clay loam soil. Banting (1967) indicated triallate was unavailable to wild oats at moisture levels below the hygroscopic point in the Regina heavy clay soil. The hygroscopic point is the moisture content in soil that is in equilibrium with air at 98% relative humidity, or equivalent to an applied pressure of 2700 kPa. The pressure at the permanent wilting point is 1500 kPa. The Regina heavy clay soil contained about 14% moisture at the hygroscopic point. In the field, the soil can be at an adequate moisture level for seed germination at seeding depth but extremely dry at the surface. In one test, soil moisture levels in a loam soil varied from about 2% at the surface to 17% at the 3-cm depth (Jackson, 1973).

Soil Temperature

Adsorption processes are exothermic while desorption processes are endothermic in nature, thus, increases in temperature should reduce adsorption and favor desorption (Bailey and White, 1964). In adsorption experiments, however, temperature sometimes has little effect on the amount of herbicide adsorbed (Bailey and White, 1964). With trifluralin, for example, there was no significant difference between the amounts adsorbed to soil at 7 and 27°C (Moyer, 1979).

Exchangeable Cation

It has been suggested that strongly electronegative cations (NH_4^+ Ca^{2+} Al^{3}) can polarize the carbamate linkage in triallate molecules and attract triallate to cations on soils colloids through a CO^- to M^+ bond (McGregor, 1976). This co-ordination of triallate and other organic molecules with cations on clay surfaces has been demonstrated with dry clay, but the addition of water tends to displace the organic molecule (Dowdy and Mortland, 1968; Khan, 1973). It is possible that this mechanism explains the large decrease in triallate and trifluralin vapor pressure in extremely dry soil. In dry soils, if cations of low electronegativity are on the exchange sites, the amount of herbicide bonded to soil colloids may decrease.

Soil pH

Soil pH can have an effect on the adsorption of s-triazines such as atrazine (Weber, 1970) but has little effect on the adsorption of triallate (Grover, 1974) and probably has little effect on the adsorption of trifluralin. Weak bases such as atrazine are more strongly adsorbed to clays at low soil pH.

Soil Aggregate Size

Small soil crumbs have resulted in lower concentrations of herbicides in solution than have large soil crumbs (Hance, 1976). Although it is possible that herbicides will eventually diffuse into large soil aggregates or clods, this process will likely be very slow. Therefore, the effective surface area available for the adsorption of herbicides will be smaller in soil with large clods; the concentration of herbicide in the air and water between large clods could be greater than in soil that has been tilled to form fine crumbs.

BIOAVAILABILITY OF SOIL-APPLIED HERBICIDES

In moist conditions, soils with high organic matter content have the largest adsorption capacity for herbicides and the highest rates are required for weed control. Experiments in the growth chamber with 11 Manitoba soils at 17, 22, and 27°C (Fig. 1) indicate that the correlation between the amount of trifluralin required to reduce wild oat growth by 90% (GR_{90}) and percent organic matter (OM) is about 0.90.

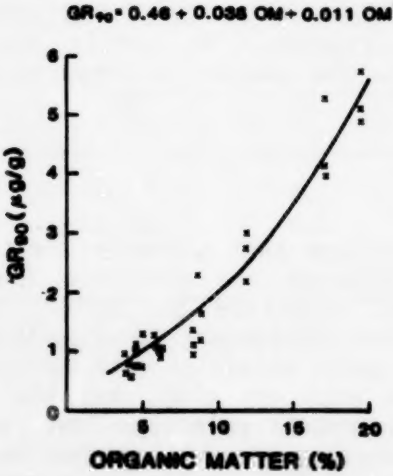

Fig. 1 Effect of organic matter on trifluralin GR_{90}. (From Moyer, 1979).

Harrison *et al.* (1976) found similar relationships between trifluralin or atrazine and the organic matter content of North Carolina soils. Experiments with a limited number of Saskatchewan soils suggest a similar correlation would exist between the amount of triallate required for wild oat control and organic matter content (McKercher *et al.*, 1975). In experiments with five Saskatchewan soils, Grover *et al.* (1979) found GR_{50} values (concentration required to reduce *Rodney* oat shoot growth by 50%) were highly correlated with organic matter content with diallate, triallate, and trifluralin. These results indicate that it should be possible to precisely match field recommendations with soil organic matter content. Walker (1980) demonstrated the problem with making these precise recommendations for field applications (Fig. 2). In the greenhouse experiment, increasing organic matter from soil 1 to soil 4 indicates separate rates of application are required to give acceptable control (R_1 to R_4). In the field, increasing variability leads to overlapping of response curves, and it becomes more realistic to group soils so that only two rates, R_5 and R_6, are required to allow for the differences in soil type. This, of course, is the current situation with recommendations for wild oat herbicides which are described by Grover *et al.* (1979).

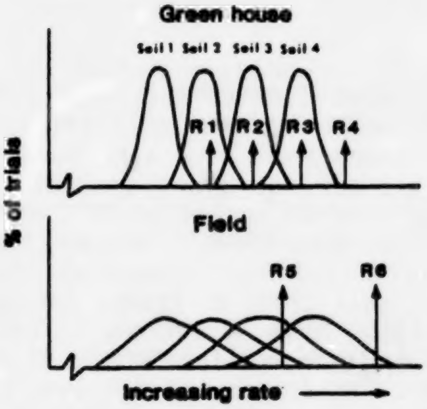

Fig. 2 Comparison of the activity of a herbicide in different soils in the greenhouse and the field. Soil organic matter increases from Soil 1 through Soil 4. R_1 to R_6 are the rates for 90% weed kill. (From Walker, 1980)

Some of the reasons for variability of control in the field are related to the factors that control adsorption to soil. Soil moisture, for example, could cause large changes in the availability of herbicides for plant uptake. An experiment conducted by Banting (1967) demonstrates that diallate is not effective in extremely dry soil (Table 2).

Table 2 Control of wild oat by diallate at different moisture levels of Regina heavy clay soil

Initial moisture* of treated soil %	Diallate application (kg/ha) 0.28	0.56	1.1
	----------% control--------		
0	0	0	0
5	0	0	0
10	0	0	0
15	67	95	100
20	74	100	100
25	82	100	100

*For Regina heavy clay soil: permanent wilting point = 20% and hygroscopic point = 14%. (Adapted from Banting, 1967)

With herbicides such as atrazine, which are likely carried to wild oat roots by the mass flow of water caused by transpiration, limited soil moisture would reduce transpiration, herbicide uptake, and translocation. Temperature may also have an effect on the availability of herbicides for plant uptake. Triallate caused greater reductions in wild oat growth at 20°C than at 10°C (Miller and Nalewaja, 1976). Darwent (1980), however, found that wild oat control with trifluralin did not improve as the temperature increased. The size of soil clods or crumbs following herbicide incorporation could produce large variations in the amount of herbicide while wild oats could emerge from within the clods with little exposure to herbicide. McKercher and McGregor (1980) also demonstrated that NH_4^+- levels in soil have an effect on either the adsorption of triallate to soil or cell permeability and transport processes within the plant, producing better wild oat control following the application of NH_4^+-N.

In addition to the effect of environmental stresses on herbicide adsorption to soil, these stresses probably have an effect on how the plant responds to available herbicide.

Soil moisture is one of the most important environmental stresses causing variations in herbicide efficacy. Rainfall can not be controlled but every attempt should be made to conserve soil moisture in herbicide incorporation. In some instances where soil is extremely dry, soil-applied herbicides should not be used. Tillage of wet soil, which leads to the formation of large soil clods, poor distribution of herbicide, and rapid drying of the top

1 to 5 cm of soil, should be avoided. Thus, some attempts can be made to achieve the ideal levels of wild oat control that are achieved under controlled environmental conditions.

REFERENCES

Bailey, G. W., and J. L. White. 1964. Review of adsorption and desorption of organic pesticides by soil colloids with implications concerning pesticide bioactivity. J. Agr. Food Chem. 12:324-332.

Banting, J. D. 1967. Factors affecting the activity of di-allate and tri-allate. Weed Res. 7:302-315.

Beestman, G. B., and J. M. Deming. 1976. Triallate mobility in soils. Weed Sci. 24:541-544.

Darwent, A. L. 1980. Effects of soil temperature on the phytotoxicity of trifluralin to wild oats. Can. J. Plant Sci. 60:929-938.

Dowdy, R. H., and M. M. Mortland. 1968. Alcohol-water interactions on montmorillonite surfaces. II. Ethylene glycol. Soil Sci. 105:36-43.

Grover, R. 1974. Adorption and desorption of trifluralin, triallate, and diallate by various adsorbents. Weed Sci. 22:405-408.

Grover, R., J. D. Banting, and P. Morse. 1979. Adsorption and bioactivity of di-allate, tri-allate, and trifluralin. Weed Res. 19:363-369.

Hance, R. J. 1976. The effect of soil aggregate size and water content on herbicide concentration in soil water. Weed Res. 16:317-321.

Harper, L. A., A. W. White Jr., R. R. Bruce, A. W. Thomas, and R. A. Leonard. 1976. Soil and micro-climate effects on trifluralin volatilization. J. Environ. Qual. 5:236-242.

Harrison, G. W., J. B. Weber, and J. V. Baird. 1976. Herbicide phytotoxicity as affected by selected properties of North Carolina soil. Weed Sci. 24:120-126.

Jackson, R. D. 1973. Diurnal changes in soil water content during drying. In Field soil water regime. SSSA Spec. Pub. No. 5. Madison, WI.

Khan, S. U. 1973. Interactions of S-2,3,3-trichlorallyl N, N-diisopropylthiol carbamate (triallate) with montmorillonite. J. Environ. Qual. 2:415-417.

McGregor, W. R. 1976. Effect of cations on triallate efficacy. Ph.D. Thesis. Univ. Saskatchewan, Saskatoon, SK.

McKercher, R. B., R. Ashford, and R. E. Morgan. 1975. Effects of triallate on wild oats grown in a growth chamber. Weed Sci. 23:283-285.

McKercher, R. B., and W. R. McGregor. 1980. Triallate phytotoxicity and nitrogen fertilization. Weed Sci. 28:740-744.

Miller, S. D., and J. D. Nalewaja. 1976. Phytotoxicity of triallate vapors to wild oat. Weed Sci. 24:134-136.

Moyer, J. R. 1971. Some aspects of adsorption and desorption of herbicides with soil colloids. Ph.D. Thesis. Univ. Saskatchewan, Saskatoon, SK.

Moyer, J. R. 1979. Soil organic matter, moisture, and temperature: Effect on wild oats control with trifluralin. Can. J. Plant Sci. 59:763-768.

Moyer, J. R. P. N. P. Chow, and R. D. Dryden. 1981. Triallate herbicide application with dry and solution nitrogen fertilizers. Can. J. Plant Sci. 61:107-114.

Schmidt, R. R., and W. Pestemer. 1980. Plant availability and uptake of herbicides from soil, p. 179-201. In R. J. Hance (ed.) Interactions between herbicides and the soil. Academic Press, London.

Scott, H. D., and J. F. Lutz. 1971. Release of herbicides from clay minerals as a function of water content: I. Kaolinite. Soil Sci. Soc. Amer. Proc. 35:374-379.

Smith, A. E. 1970. Degradation, adsorption, and volatility of diallate and triallate in prairie soils. Weed Res. 10:331-339.

Swann, C. W., and R. Behrens. 1972. Phytotoxicity of trifluralin vapors from soil. Weed Sci. 20:143-146.

Walker, A. 1980. Activity and selectivity in the field, p. 203-222. In R. J. Hance (ed.) Interactions between herbicides and the soil. Academic Press, London.

Weber, J. B. 1970. Mechanisms of adsorption of s-triazines by clay colloids and factors affecting plant availability, p. 93-103. In G. A. Gunther (ed.) Residue Reviews. Vol. 32. Springer-Verlag, New York.

WILD OAT DORMANCY WORKSHOP

NEW METHODS FOR BREAKING SEED DORMANCY AND THEIR APPLICATION IN WEED CONTROL

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ABSTRACT

Real advances in weed control can be achieved by reducing viability of the huge dormant weed seed populations in agricultural soils. Theoretically, this could be accomplished by breaking dormancy and inducing seed germination. Ethylene was utilized to stimulate germination of witch weed (Striga asiatica [L.] Kuntze.) seeds and reduce the number of dormant seeds remaining in infested soils. This new approach enhanced control of the parasitic weed in the United States. Attempts to use germination stimulants (ethylene, sodium azide, nitrates) to similarly reduce seed populations of other weed species indicated that some reductions were possible under certain conditions. Other germination stimulants (e.g. strigol, ethanol) or treatments to increase seed coat permeability should be considered in future studies. For further advances in this new approach, research is needed to gain a better understanding of weed seed secondary dormancy in the field, to discover new stimulants that can be used in soil, and to develop controlled-release procedures to maximize and prolong the effect of the stimulants.

IMPORTANCE OF WEED SEED DORMANCY

Dormant weed seeds constitute a major barrier to complete exploitation of advances in weed control. This fact was recognized over 20 years ago (Harper, 1959) and it is still true today (Chancellor, 1982). It is not uncommon for agricultural soils to contain up to 80,000 weed seeds per square meter (Harper, 1977). Some of these seeds may remain dormant and viable for many years, even decades. Also, seeds of the population may break dormancy and germinate at different times, thus giving rise to weed stands over a period of time. This requires the grower to cope repeatedly with the same weed problems.

Except for severe soil sterilization techniques, current weed control practices have little effect upon dormant seeds because the action of most modern herbicides is limited to post-germination plant stages. Even if all target weeds are killed by a single herbicide treatment, and no new seeds are produced, dormant seeds already in the soil will remain to germinate later and produce future weed problems. Real advances in weed control could be achieved if weed seeds in the soil could be induced to germinate simultaneously, thus reducing the dormant seed population and reducing the time during which weed control treatments will be necessary. Fewer weed control treatments would be necessary to control weeds arising from a given seed population. This theory of improved weed control has been considered previously, but the science and technology to put it into general use are lacking. Chancellor (1982) suggested that the next major improvement in weed control will be the decrease of weed seed populations with chemical seed germination stimulants.

TYPES OF DORMANCY

In simple terms, a seed may be considered to be dormant if it does not germinate under conditions favorable for seedling growth and development. Germination may be considered to be the resumption of growth of the embryo which results in protrusion of a portion of the embryo (usually the radicle) through the seed coverings. Factors preventing the resumption of embryo growth may reside in coverings around the embryo or in the embryo itself. The coverings may block water or oxygen uptake, impede carbon dioxide exchange, contain inhibitors of embryo growth, physically prevent embryo expansion, or block light penetration (Werker, 1980/81). The embryo may have a hormone imbalance or it may have one or more physiological or biochemical deficiencies or disorders that must be corrected or put in order before germination can occur. Factors in both coverings and embryo may combine to cause dormancy.

Primary and secondary dormancy are two major kinds of dormancy (Karssen, 1980/81). Seeds that are dormant at the time of dispersal from the parent plant are in primary dormancy. Seeds that were nondormant at dispersal or had their primary dormancy broken but were unable to germinate because of adverse conditions may then pass into secondary dormancy. An example of primary dormancy is that of seeds produced in autumn in a moderate climate that require low temperature overwintering to break primary dormancy before germination can occur in the warm, spring temperatures that follow. However, adverse conditions (i.e. prolonged low temperatures, dry soil, lack of O_2) may prevent germination and cause the acquisition of secondary dormancy. Secondarily dormant seeds will not germinate even when conditions again become favorable for germination but will require another dormancy-breaking treatment. According to Harper (1959), some seeds are "born" dormant (primary dormancy) and some seeds acquire dormancy (secondary dormancy).

In the field, seeds may be in either type of dormancy, but secondary dormancy probably predominates in seeds that remain dormant for several years in the imbibed condition. There is evidence that some seeds pass through cycles of ability to germinate that are probably due to the repeated acquisition and loss of secondary dormancy (Karssen, 1980/81). More knowledge of the dormancy state of weed seeds at various times of the year will be important in determining the optimum time to apply a germination stimulant. Therefore, more research on dormancy conditions of weed seeds in the field is needed.

ETHYLENE-ENHANCED CONTROL OF WITCH WEED IN THE UNITED STATES

There is one major example of the use of a germination stimulant to improve weed control. Ethylene, the well known germination stimulant, enhanced the control of witch weed (*Striga asiatica* [L.] Kuntze) in the United States (Egley, 1982; Eplee, 1975). Witch weed is an obligate root parasite of corn (*Zea mays* L.) and many other warm-season grasses. This parasitic plant was accidentally introduced into the United States sometime prior to 1956. In nature, the long-lived, dormant witch weed seeds are induced to germinate by one or more chemical stimulants exuded from plant roots. This is an excellent survival mechanism as germination is limited, therefore, to the root zone where chances are increased for parasitism of the host root by the seedling. Research was conducted to discover other compounds that induce witch weed seed germination in the absence of the host. It was learned that ethylene at low concentrations (0.01 μl/1) induced witch weed seed germination and that ethylene was also effective on witch weed seeds in the soil (Egley and Dale, 1970). Methods for applying ethylene in the field to induce witch weed seed germination were developed by USDA-Animal and Plant Health Inspection (APHIS) personnel and up to 6000 ha of witch weed infested fields per year were treated in 1981 (Egley, 1982). Seedlings that did not manage to parasitize a host were controlled with conventional herbicides. Tests indicated that soil populations of witch weed seeds were reduced by up to 90% in the ethylene-treated fields (Eplee, 1975). Therefore, ethylene was an important tool in the witch weed control program in the United States and was used in combination with conventional control measures to reduce the soil populations of viable seeds.

There are several reasons for the success of ethylene as a soil-applied germination stimulant of witch weed seeds. Witch weed seeds are very sensitive to ethylene and only 2 hours of contact with the gas is necessary to trigger germination. Also, light sandy soils predominate throughout the witch weed infested area of the United States. These soils facilitate both application of the gas and its diffusion as far as 90 cm below and 120 cm lateral to the point of application (Eplee, 1975).

Ethylene effects on other weed seeds in the field have not been demonstrated. However, ethylene does stimulate seed germination of several weed species (Taylorson, 1979). Under growth chamber conditions, ethylene induced germination of common cocklebur (Xanthium pensylvanicum Wallr.) and redroot pigweed (Amaranthus retroflexus L.) in soil (Egley, 1980). Attempts to significantly induce germination of these weed seeds in the field with ethylene have not been successful. Further research is needed to determine whether germination of other weed seeds can be stimulated by ethylene in the field.

AZIDE STIMULATION OF WEED SEED GERMINATION

In laboratory tests, inhibitors of respiration were found to break dormancy of several species of weed seeds (Hendricks and Taylorson, 1974; Roberts, 1973). Fay and Gorecki (1978) tested sodium azide for activity on wild oat (Avena fatua L.) in the field and found that azide produced up to a fourfold increase in emergence of wild oat as compared to untreated controls. Because their results were inconsistent, they concluded that azide was not practical for use as a germination stimulant unless adequate means were developed for the controlled-release of the material (Fay et al., 1980). In other studies, Hurtt and Taylorson (1980) found that azide increased grass emergence 97% over that of the untreated controls but broadleaf weed emergence was not significantly increased. Therefore, the potential for azide enhanced control of grass weeds exists if adequate means of controlling azide release in the soil can be developed. Safe handling of azide is a factor in its use as a germination stimulant.

NITRATE STIMULATION OF WEED SEED GERMINATION

Nitrates are known to stimulate weed seed germination, particularly the light-sensitive seeds (Steinbauer and Grigsby, 1957). Taylorson (1969) suggested that nitrate fertilization might result in increased weed seed germination when the soil was disturbed and seeds were also exposed to light. Although Fawcett and Slife (1978) were unable to increase germination of common lamb's quarters (Chenopodium album L.), giant foxtail (Setaria faberi Herrm.), velvet-leaf (Abutilon theophrasti Medic.), jimson-weed (Datura stramonium L.), or redroot pigweed in the field following up to 336 kg/ha ammonium nitrate, they did find that common lamb's quarters seeds harvested from the nitrate plots were less dormant than seeds from control plots. Thus the nitrate effect was not immediately apparent, but long-term effects such as reduced dormancy and reduced longevity of seeds produced by plants receiving the nitrate might result. Schmipf and Palmblad (1980) also found that nitrate fertilization did not increase the germination of redroot pigweed and yellow foxtail (Setaria glauca [L.] Beauv.) seeds that were given overwintering treatments.

Perhaps the potential for nitrates in inducing weed seed germination resides in combined effects with other stimulating treatments such as light, chilling or alternating temperatures (Vincent and Roberts, 1979). Nitrates seem to increase the sensitivity of seeds of several weed species to other stimulants. Also, it is interesting that nitrate fertilization might result in subtle, long-term effects such as reduced dormancy of new seeds.

STRIGOL STIMULATION OF PARASITIC WEED SEED GERMINATION

Strigol was isolated and identified as a witch weed seed germination stimulant in exudates from cotton roots (Cook *et al.*, 1972). This highly potent stimulant induced witch weed seed germination at concentrations as low as 10^{-12} M. Research with strigol is continuing in order to determine if a stimulant more active than ethylene might be developed to further enhance witch weed control. It is of additional interest that strigol and strigol analogues were found to stimulate seed germination of species of *Alectra* and *Orobanche* which are also parasitic plants (Visser and Johnson, 1982; Johnson *et al.*, 1976). Preliminary tests indicated that one analogue had some activity on *Striga* when applied to soil (Babiker and Hamdoun, 1982).

Effects of strigol compounds upon weed seeds other than those of parasitic plants have not yet been demonstrated, although there is some indication that lettuce seed germination might be increased under certain conditions (Bradow, 1982). Strigol is a stimulant of parasitic weed seed germination and the general growth stimulating properties of strigol have not yet been thoroughly explored.

STIMULATION OF GERMINATION BY OTHER COMPOUNDS

Gibberellins and cytokinins are two groups of compounds that can sometimes induce germination of several weed seeds. Gibberellic acid often substitutes for a light requirement and cytokinins were considered to permit the action of other germination stimulants, particularly gibberellins (Kahn, 1980/81). A substituted phthalimide exhibited gibberellin-like activity in inducing seed germination of wild oats and four other weed species (Metzger and Suttle, 1982). Fusicoccin is another compound known to induce seed germination. However, information is lacking on the activity of all these compounds in soil.

Other compounds with dormancy breaking capabilities include inhibitors such as cyanide and hydroxylamine which like azide, inhibit terminal oxidase activity. Other respiratory inhibitors that also break dormancy include nitrate, iodoacetate and thiourea (Roberts, 1973; Hendricks and Taylorson, 1974). Low oxygen levels were also found to induce weed seed germination (Esashi *et al.*, 1976). Therefore, it seems that treatments capable of breaking dormancy are not limited to those that promote growth or metabolism in plants. This points out that dormancy is indeed a complex and poorly understood process.

More recently ethanol and some other anesthetics were shown to promote seed germination of several grass weed species in the laboratory (Taylorson and Hendricks, 1979). These compounds should be considered for testing in soil. Low concentrations of carbamate herbicides stimulated germination of common lamb's quarters, velvet-lead and giant foxtail seeds and caused increased field stands of these weeds (Fawcett and Slife, 1975). Therefore, a wide variety of compounds are capable of breaking dormancy and increasing weed seed germination.

PHYSICAL TREATMENTS TO INDUCE SEED GERMINATION

A significant number of weed seeds have "hard" impermeable coats or coverings that cause seed dormancy. Many weed seeds with coats impermeable to water are long-lived and impose serious weed problems. Acid or physical scarification, freeze-thawing, impaction, sonication or hot water soaks have induced water uptake and promoted germination of seeds with impermeable coats (Holm and Miller, 1972). In some instances, coat scarification enhanced germination of imbibed seeds. Therefore, coat treatments may also remove a restraint to gas exchange or embryo expansion and, thereby, permit germination.

Moist heat treatments in the laboratory have accelerated afterripening of weed seeds and improved germination with time (Taylorson and Brown, 1977). Also, elevation of soil temperatures by solar heating of field plots through transparent mulch may break dormancy of some weed species (Egley, in press). Leather and French (1980) reported that some volatile aldehydes induced swelling and imbibition of water by hard weed seeds. Sodium hypochlorite treatments induced germination of weed seeds, presumably because of effects upon seed coat permeability (Hsiao, 1980). Although an attack on the hard seeds in the soil may be difficult to envision, research to increase the seed coat permeability of these seeds in soil should be pursued.

RESEARCH NEEDS

Problems to be solved in achieving reductions in dormant weed seed populations in the soil are formidable but results indicate that they are not unsolvable. It is unlikely that an entire weed seed population, or seeds of all species in a population, in a given field or location, can be induced to germinate by a few treatments. Seed dormancy mechanisms are well established biological means of survival and it will be difficult to counteract them. However, through a better understanding of these dormancy mechanisms, the discovery of how to regulate the key processes, and by the development of technology necessary to use the dormancy-regulating treatments in agriculture, we can make inroads in manipulating weed life cycles and reducing their impact upon crops.

Research is needed to better understand factors influencing the fluctuations in secondary dormancy of weed seeds in the field. Times when weed seeds have maximum sensitivity to external stimuli (e.g., light, ethylene, temperature) should be determined so that the stimuli can be applied to the greatest effect. The mechanisms by which seeds sense and respond to external stimuli need to be better understood. The search for additional germination stimuli should be pursued. Investigations into the possible allelopathic effects of plant exudates or leachates upon seed germination may reveal new compounds for germination regulation. We know that plant roots exude stimulants of witch weed seed germination. Detection and identification of other natural stimuli, with subsequent synthesis of active materials, could result in safe treatments for the manipulation of weed seed germination in the field. There is also a need to utilize controlled-release technology in order to put a stimulant in the right place at the right time and maintain it long enough to induce germination. In agricultural situations, the methods or chemicals used to break weed seed dormancy must be safe and without hazard to man or the environment.

REFERENCES

Babiker, A. G. T., and A. M. Hamdoun. 1982. Factors affecting the activity of GR7 in stimulating germination of Striga hermonthica (Del.) Benth. Weed Res. 22:111-115.

Bradow, J. M. 1982. Structure-activity relationships of strigol and synthetic analogs in the regulation of lettuce seed germination. Plant Physiol. (Ann. Suppl.) 69:2.

Chancellor, R. J. 1982. Dormancy in weed seeds. Outlook on Agric. 11:87-93.

Cook, C. E., L. P. Whichard, M. E. Wall, G. H. Egley, P. Coggon, P. A. Luhan, and A. T. McPhail. 1972. Germination stimulants. I. The structure of strigol, a potent seed germination stimulant for witch weed (Striga lutea Lour.). J. Am. Chem. Soc. 94:6198-6199.

Egley, G. H. 1980. Stimulation of common cocklebur (Xanthium pensylvanicum) and redroot pigweed (Amaranthus retroflexus) seed germination by injections of ethylene into soil. Weed Sci. 28:510-514.

Egley, G. H. 1982. Ethylene stimulation of weed seed germination. Agric. and Fores. Bull. Univ. of Alberta 5: 13-18.

Egley, G. H. (In press). Weed seed and seedling reductions by soil solarization with transparent polyethylene sheets. Weed Sci.

Egley, G. H., and J. E. Dale. 1970. Ethylene, 2-chlorethylphosphonic acid, and witch weed germination. Weed Sci. 18:586-589.

Eplee, R. E. 1975. Ethylene: A witch weed seed germination stimulant. Weed Sci. 23:433-436.

Esashi, Y., K. Kotaki, and Y. Ohhara. 1976. Induction of cocklebur seed germination by anaerobiosis: A question about the "inhibitor hypothesis" of seed dormancy. Planta. 129:109-112.

Fawcett, R. S., and F. W. Slife. 1975. Germination stimulation properties of carbamate herbicides. Weed Sci. 23:419-424.

Fawcett, R. S., and F. W. Slife. 1978. Effects of field applications of nitrate on weed seed germination and dormancy. Weed Sci. 26:594-596.

Fay, P. K., and R. S. Gorecki. 1978. Stimulating germination of dormant wild oat (Avena fatua) seed with sodium azide. Weed Sci. 26:323-326.

Fay, P. K., R. S. Gorecki, and P. M. Fuerst. 1980. Coating sodium azide granules to enhance seed germination. Weed Sci. 28:674-677.

Harper, J. L. 1959. The ecological significance of dormancy and its significance in weed control. Internat. Conf. Crop Prot. Proc. 4:415-420.

Harper, J. L. 1977. Population biology of plants. Academic Press, New York.

Hendricks, S. B., and R. B. Taylorson. 1974. Promotion of seed germination by nitrate, nitrite, hydroxylamine, and ammonium salts. Plant Physiol. 54:304-309.

Holm, R. E., and M. R. Miller. 1972. Weed seed germination responses to chemical and physical treatments. Weed Sci. 20:150-153.

Hsiao, A. I. 1980. The effect of sodium hypochlorite, gibberellic acid and light on seed dormancy and germination of stinkweed and wild mustard. Can. Jour. Plant Sci. 60:643-649.

Hurtt, W., and R. B. Taylorson. 1980. Further studies on azide-stimulated weed emergence. Northeastern Weed Sci. Proc. 34:112.

Johnson, A. W., G. Rosebery, and C. Parker. 1976. A novel approach to *Striga* and *Orobanche* control using synthetic germination stimulants. Weed Res. 16:223-227.

Kahn, A. A. 1980/81. Hormonal regulation of primary and secondary seed dormancy. Israel Jour. Bot. 29:207-224.

Karssen, C. M. 1980/81. Environmental conditions and endogenous mechanisms involved in secondary dormancy of seeds. Israel Jour. Bot. 29:45-64.

Leather, G. R., and R. C. French. 1980. Increased imbibition of dormant smartweed seed by nonanal and related flavor volatiles. Plant Physiol. (Ann. Suppl.) 65:139.

Metzger, J. D., and J. C. Suttle. 1982. Gibberellin-like activity of a substituted phthalimide. Plant Physiol. (Ann. Suppl.) 69:24.

Roberts, E. H. 1973. Oxidative processes and the control of seed germination, p. 189-218. In W. Heydecker (ed.) Seed ecology. Butterworth, London.

Schimpf, D. J., and I. G. Palmblad. 1980. Germination response of weed seeds to soil nitrate and ammonium with and without simulated overwintering. Weed Sci. 28:190-193.

Steinbauer, G. P., and B. Grigsby. 1957. Interaction of temperature, light and moistening agent in the germination of weed seeds. Weeds 5:175-182.

Taylorson, R. B. 1969. Photocontrol of rough cinquefoil seed germination and its enhancement by temperature manipulation and KNO_3. Weed Sci. 17:144-148.

Taylorson, R. B. 1979. Response of weed seeds to ethylene and related hydrocarbons. Weed Sci. 27:7-10.

Taylorson, R. B., and M. M. Brown. 1977. Accelerated afterripening for overcoming seed dormancy in grass weeds. Weed Sci. 25:473-476.

Taylorson, R. B., and S. B. Hendricks. 1979. Overcoming dormancy in seeds with ethanol and other anesthetics. Plant. 145:507-510.

Vincent, E. M., and E. H. Roberts. 1979. The influence of chilling, light and nitrate on the germination of dormant seeds of common weed species. Seed Sci. and Technol. 7:3-14.

Visser, J. H., and A. W. Johnson. 1982. The effect of certain strigol analogues on the seed germination of *Alectra*. South Afr. J. Bot. 1:75-76.

Werker, E. 1980/81. Seed dormancy as explained by the anatomy of embryo envelopes. Israel Jour. Bot. 29:22-44.

AWN ANATOMY AND ITS RELATION TO GERMINABILITY OF WILD OAT CARYOPSES

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ABSTRACT

Many envelopes surround the embryo in a floret-enclosed caryopsis of wild oats (Avena fatua L.). The awn is a modified part of the lemma-envelope and the dry mature awn has a proximal twisted portion and a distal untwisted awl. The proximal part is made up of the adaxial and abaxial ridges, and the connective between the two. The fibre cells associated with these three parts are capable of shrinking and stretching depending on water availability. Only the proximal portion can perform the twisting and untwisting; the awl is passive and may act as a brace. The awn, while untwisting, produces tremendous torsion and dislodges the associated caryopsis from the spikelet. The caryopses can be retained longer on spikelets by clipping the awls. The deawled-caryopses retained longer on the inflorescence mature better and show greater germinability than the awled-caryopses which is dislodged due to awn movement. This difference in the germinability between deawled and awled caryopses may be attributed to the developmental delay or arrest in the embryo and its important envelope, the endosperm. Such an adaptive mechanism provides wild oats with a large "seed reserve" to last for several seasons.

Many envelopes surround the embryo in an angiospermous seed (Werker, 1980/81). They play an important role in the permeability of water, oxygen, etc., and also in offering physical restraint to embryo emergence during seed germination. Some of these envelopes do influence the growth of the embryo in the early stages of seed development. In many grasses, the awn, a part of the lemma-envelope is reported to be physiologically efficient in the transpiration and photosynthesis, and increases grain yield in some cereals (Grundbacher, 1963). In addition, the mature awn with its scabrous texture and the ability to perform hygroscopic movement, may deter many seed predators or help in the dispersal of fruits (Darwin, 1876; Schmid, 1898). It is also reported that the awns in some instances may aid in the burial of caryopses to overcome unfavorable conditions (Lock and Milburn, 1971).

While it is deeply embedded in literature that the wild oat awns indeed aid in the burial of the floret-enclosed caryopses into the ground (Harper, 1977; Stinson and Peterson, 1979) the results of a recent investigation contradict this putative function (Raju and Ramaswamy, 1983). Evidences have been provided to indicate that the untwisting-twisting movement of the mature awns helps to dislodge caryopses prematurely from the inflorescence. Such caryopses doubtless contain embryos and endosperm of different stages of development which may be responsible for non-uniform caryopses germinability. This feature would allow the species to maintain a reserve of propagules for many seasons (Johnson, 1935).

Earlier greenhouse and growth-chamber experiments on wild oats showed that the caryopses were dropped periodically to the ground by awn movement, possibly prematurely (Raju and Ramaswamy, 1983). Such caryopses showed low and irregular germination. A review of the literature showed very little information on the structure and organization of the wild oat awn. A few investigations were undertaken to study the anatomy of the awn in relation to movement and a part of the results is presented here. Results of a study also suggested that the caryopses could be retained on the inflorescence by deawling their awns (Rajú and Ramaswamy, 1983). It was hypothesized that such caryopses retained longer on parent plants, would mature better and show greater and more uniform germinability. Some results of experiments conducted to determine the germinability differences, if any, between deawled and non-deawled caryopses, are included and discussed.

In a spikelet just emerged from the flag-leaf sheath, the awn contains two distinct parts, the green distal awl or subule and the brownish-green proximal portion; the awl is always longer. The proximal portion has two longitudinally arranged ridges alternating adjacently with two longitudinal furrows. The two ridges, the wider adaxial and the narrower abaxial, continue distally into the awl where the width difference between them is not obvious. On the awn contain forwardly directed unicellular hairs or spicules, and consequently the awn remains scabrous. The furrows placed adjacent to the ridges are more conspicuous in the proximal part of the awn than in the awl and contain chlorenchyma.

Anatomically the distal and proximal portions of a young awn are very similar and the thin-walled ground parenchyma including chlorenchyma, contain chloroplasts. The cell walls show birefringence typical of primary walls. The single vascular bundle in the proximal part of the awn lies in the abaxial ridge and in the awl it is more centrally placed between two ridges. The chlorenchyma in the proximal portion forms c-shaped wedges which in the awl are less pronounced.

After fertilization the tissues in the awn gradually lose water and undergo tremendous changes, especially in the proximal portion. The cell-wall thickening in the ground parenchyma increases gradually and it is relatively more in the proximal portion than in the awl. The major bulk of the thickening is due to secondarily deposited cellulose fibrils and it can be identified by staining with chlor-zinciodide solution. Similarly, abundant pectic substances in the cell wall may be recognized by using ruthenium red. The thick cell-walls in the proximal portion of the awn contain conspicuous simple and ramified pits, and often show characteristic lamellations especially when the cells are twisted. These specialized cells are confined to the ridges and to the region connection the two ridges, and have been designated as "fiber cells." Because of the twisting and untwisting of the ridges and the connective in between, the chlorenchyma with its epidermis is obliterated and it persists as thin papery remains which may act as blotters. The cell walls in the awl are not as thick as those in the proximal part and the cells, alone or in group, do not show twisting-untwisting movement. The mature dry awn with is twisted proximal portion and the untwisted awl placed at an angle, appears geniculate.

The fiber cells in the proximal part, are isodiametric and compactly arranged with little or no intercellular space. In an untwisted state the fiber cells contain on their radial and tangential walls characteristic helically arranged pits indicating the helical arrangement of the microfibrils. The cell walls contain abundant cellulose and pectic materials, and are highly birefringent, especially in non-aqueous media, similar to secondary walls. The fibre cells can be isolated from macerations and are capable of shrinking and stretching depending respectively on the dryness and wetness of the environment.

The length of isolated fiber cells is quite variable and it increases from the center of the connective to the periphery of the ridges. Concomitantly the pattern of shrinkage of individual cells is variable and interesting. The shorter, more centrally situated cells tend to decrease in length by straight longitudinal compression. The longer cells in the periphery, especially in the ridge, shorten by twisting and/or twining. The extent of stretching or shrinking of the most central fiber-cells is greater than that in cells of the ridges.

Every fiber-cell (except the epidermal spicules) in the ridges and the central connective has the ability to change its length, depending on whether there is moisture in the environment or not. Althought the basic mechanism is manifested in individual cells (Preston, 1974), the awn movement in wild oats is an integrated one involving three components, the adaxial-abaxial ridges and the connective joining the two ridges. In addition, the furrows formed as a result of chlorenchyma obliteration, behave as channels or capillaries transporting water from one end to the other. The water must first enter the furrows and wet the dry cells of the connective and also of the ridges of a geniculate awn. The cell walls of the central fibers stretch longitudinally making the adjacent and subjacent cells of ridges also stretch and untwist. The straight longitudinal stretching of cells in the middle of the connective and the stretching of the obliquely placed twisted cells in the peripheral parts of the ridges make the proximal part of the awn to untwist in the clockwise direction. Consequently, the awn changes from geniculate condition to straight position. It seems, therefore, whatever the mechanism at the molecular level, the structure and disposition of tissues are well organized for a predictable type of movement in the awn.

The awn, by its untwisting-twisting movement, dislodges the floret enclosed caryopses prematurely. Ordinarily, the secondary caryopsis, which is initiated later than the primary caryopsis in a spikelet, drops earlier by awn movement. The floret arrangement is such that the secondary caryopsis can drop without disturbing the primary. But a dislodged primary will also dislodge the secondary. The dry awn in a mature floret-enclosed caryopis on wetting, untwists and produces tremendous torsion while the awl acts as a brace. The torsion produced by the awn while untwisting is $T = 15.01 \times 10^{-5}$ N.m which is more than that ($T = 3.38 \times 10^{-5}$ N.m) needed to dislodge the caryopsis from its pedicel in laboratory experiments. The untwisting awn, with its awl acting as a brace, exerts considerable pressure on the caryopsis which consequently turns in the opposite direction (anticlockwise) and, finally, the caryopsis is detached from the pedicel. In the field, such untwisting-twisting movement of the awn results in periodic shattering of the floret-enclosed caryopses, which doubtless contain a wide range of maturity of embryo and endosperm. However, this premature dislodging can be prevented by clipping the awls; the caryopses may be retained on the parent plant to mature better than the ones dropped by awn movement.

It is known that the primary caryopsis, because of its earlier initiation and longer retention on the spikelet, germinates better than the secondary caryopsis. Results of the germinability tests of deawled (retained for four weeks on the plant) and awled (dislodged during the period of four weeks) caryopses indicate that the former germinate better than the latter (Table 1). This may be interpreted that the caryopses, both primary and secondary,

Table 1 Mean percent germination of primary and secondary caryopses of the wild oat _Avena fatua_ L. cultivar CS 40 from different sources.

Source	Primary caryopses	Secondary caryopses
Caryopses with awls, collected on ground	39*	22**
Caryopses with awls cut, collected from plants	82	57

$^{*}p<5\%$
$^{**}p<1\%$

retained longer achieve greater maturity or "ripeness" to germinate better than the awled ones which ordinarily drop earlier. Developmental and structural changes in the caryopses are being investigated.

In a favorable environment, the seed development and germination are continuous processes in the life cycle of higher vascular plants. However, this sequence of events in non-cultivated plants is not observed because of the manifestation of many adaptive mechanisms, especially relating to reproduction. The seed is often referred to as "mature" to indicate that the embryo should emerge from the seed. Very frequently, the embryo does not reach this state of "ripeness" to germinate because of a developmental delay or arrest in it, or in the associated envelopes around it. In a recent interview, the role of a variety of envelopes in relation to seed germination has amply been described (Werker, 1980/81). The seed coat enveloping the embryo may be important in the germination of non-endosperm seeds. In endospermous seeds, the endosperm can be an important envelope influencing the embryo emergence.

The awn, which is morphologically a modified part of the lemma-envelope, contains tissues similar to those of the lemma. But, it is anatomically highly specialized to perform characteristic hygroscopic movement which does have an adaptive value in wild oats. The pattern of twisting and untwisting is maintained by the fiber tissue associated with the ridges and the connective in the proximal portion of the awn. The maturation pattern of caryopses is also significant in the survival of wild oats in the prairies. The basipetal maturation of caryopsis in the entire inflorescence, their acropetal maturation in spikelets, and their premature dislodging by awn movement, result in the shattering of caryopses with different degree of maturation; the more matured caryopses have greater germinability. Greater and more uniform germinability can be obtained by clipping the awls and retaining the caryopses longer on panicles. In addition, the envelopes around the embryo may be protective in function, or restrict the accessibility of substances to the embryo for its growth and emergence. One of the important envelopes around the embryo in wild oat caryopsis is the endosperm, which persists as a temporary barrier against substances to move across to and from the embryo; ironically, it is also an embryo-sustaining tissue. The aleurone part of the endosperm persists long after emergence of the embryo without being digested or obliterated by the embryo. Published information suggests that the aleurone layer in grasses, including wild oats, has overwhelmingly been implicated in enzyme secretion during seed germination (Haberlandt, 1890; Briggs, 1973; Simpson, 1978). It is curious indeed how a part of the endosperm, the aleurone, is, in fact, involved in starch formation during caryopses development and starch degradation during caryopses germination! In wild oats, the aleurone layer(s), which completely surrounds the embryo and endosperm, and the cells of which contain especially abundant proteins and lipids, can behave as a delicate envelope regulating the movement of substances, including water, across the layer. Any injury, such as pricking, cutting, etc. to the aleurone increases caryopses germinability. Whether the endosperm in seeds is a physical as well as a physiological barrier in caryopsis germination needs to be investigated (Werker, 1980/81). Histological and cytological investigations of embryo envelopes in relation to caryopsis development and germination of wild oats (*Avena fatua* L.) are being conducted.

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REFERENCES

Briggs, D.E. 1973. Hormones and carbohydrate metabolism in germinating cereal grains, p. 219-277. *In* B. V. Milborrow, (ed.) Biosynthesis and its control in plants. Academic Press, London.

Darwin, F. 1876. On the hygroscopic mechanism by which certain seeds are enabled to bury themselves in the ground. Linn. Soc. (Botany), Trans. 1: 149-167.

Grudbacher, F.J. 1963. The physiological function of the cereal awn. Bot. Rev. 19: 366-381.

Haberlandt, G. 1890. Kleberschicht des Gras-Endosperms als Diastase ausscheidendes Drusengewebe. Deut. Bot. Ges. Ber. 8: 40-48.

Harper, J.L. 1977. Population biology of plants. Academic Press, London.

Johnson, L.P.V. 1935. General preliminary studies on the physiology of delayed germination in *Avena fatua*. Can. J. Res., C. 13: 283-300.

Lock, J.M., and T.R. Milburn. 1971. The seed biology of *Themeda triandra* Forsk. in relation to fire. Symp. Brit. Ecol. Soc. 11: 337-349.

Preston, R.D. 1974. The physical biology of plant cell walls. Chapman and Hall, London.

Raju, M.V.S., and S.N. Ramaswamy. 1983. Studies on the inflorescence of wild oats (*Avena fatua* L.) Can. J. Bot. 61: 74-78.

Schmid, B. 1898. Bau und functionen der Grannen unserer Getreidearten. Bot. Centralbl. 76: 36-41.

Simpson, G.M. 1978. Metabolic regulation of dormancy in seeds - A case history of the wild oat (*Avena fatua*), p. 167-220. *In*

M.E. Clutter (ed.) Dormancy and development arrest. Academic Press, New York.

Stinson, R.H., and R.L. Peterson. 1979. On sowing wild oats. Can. J. Bot. 57: 1292-1295.

Werker, E. 1980/81. Seed dormancy as explained by the anatomy of embyro envelopes. Israel J. Bot. 29: 22-44.

THE ROLE OF PHOSPHORUS IN WILD OAT SEED DORMANCY

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ABSTRACT

Levels of phospholipid, phosphoprotein, nucleic acid phosphorus and acid soluble phosphorus were determined for a number of lines of wild oat differing widely in dormancy potential. The inorganic phosphorus (Pi) fraction showed the clearest correlation with dormancy. The more dormant the line, the lower the Pi level of both caryopsis and of embryo. Pi levels in the maturing caryopsis were high in the early dough stage, dropping rapidly as desiccation progresed until levels characteristic of the mature seed were attained. Dormancy of the caryopses increased as the Pi level dropped. Caryopses obtained from plants matured under reduced phosphorus nutrient supply contained reduced levels of Pi and dormant lines so treated exhibited extended periods of dormancy. Germination in nondormant caryopses was accompanied by an initial decline in Pi content until coleorhiza protrusion was general. This was followed by a massive increase in Pi as phytate reserves became available. Treatments inducing germination in otherwise dormant caryopsis triggered a similar response. A certain amount of ATP was produced in both dormant and nondormant caryopses upon imbibition. This did not account for all the Pi utilization. The Pi available to the embryo may have a major role to paly in determining whether germination proceeds.

There are sound reasons for suggesting an intimate association between phosphorus metabolism and the processes of seed dormancy and seed germination. While extensive studies on dormant cereal seeds are lacking, it is known that in nondormant caryopses there are rapid phosphorus transformations during the processes of embryo formation and of accumulation of storage reserves (Williams, 1970; Saskaki and Loewus, 1980). During the process of seed desiccation, levels of iorganic phosphorus decline, and the originally active levels of inorganic phosophorus metabolism declines to the slow turnover rates for imbibed dormant seeds of wild oats (Cuming and Osborne, 1978a, 1978b). One of the first events accompanying imbibition in nondormant cereal caryopses is a rapid increase in ATP (Obendorf and Marcus, 1974; Rodaway et al., 1979). Caryopses of cultivated cereals exhibit a rapid uptake of endogenous inorganic phosphorus upon the inception of germination (Hall and Hodges, 1966; Sutcliffe and Baset, 1973; Mayer and Marbach, 1981). The element phosphorus is a major component of most cereals, comprising up to 0.6% of the dry weight of mature wild oat caryopses (Jain et al., 1983). With so many processes tied in to phosphorus metabolism, it is not unreasonable to assume that some of them may assume a regulatory function in the initiation or the termination of seed dormancy.

We have attempted to relate levels of some of the major phosphorus-containing fractions from wild oat caryopses to the dormancy characteristics of the caryopses. Changes were not always evident. This does not exclude the possibility of internal transformations in such fractions as nucleic acids or phospholipids. Most attention is given in this presentation to those fractions where phosphorus changes with dormancy were apparent. Certain aspects of the work have been published, while others are reported for the first time.

MATERIALS AND METHODS

A number of lines of wild oats, genetically distinct, with varying degrees of primary dormancy were utilized (Naylor and Fedec, 1978). Among the dormant lines, MON 73 is strongly dormant with Idaho, AN 474 and AN51 progressively less dormant. CS 40 along with SH 319 and SH 430 were considered to be nondormant but under our conditions, CS 40 shows a certain degree of dormancy. In some determinations, Sioux, an A. sativa cultivar, was used as a standard for comparison. Seeds were harvested at maturity and held at -15°C to preserve their dormancy characteristics. Procedures for growth regimes, imbibition and germination have been described elsewhere (Jain et al., 1982, 1983; Quick et al., 1982/83). Seeds with comparable growth histories were used in all comparisons made. Work was done with entire caryopses wherever possible. If a given seed part was to be followed through a certain growth phase, every effort was made to expose the entire caryoposes to the process, excising the individual parts as required. While tedious, such a process took account of possible interactions between the seed parts.

Phosphorus fractionations followed a scheme devised for germination studies on cultivated oats (Hall and Hodges, 1966). The major phosphorus components of the caryopsis were separated into phospholipid, phosphoprotein, nucleic acid phosphorus and an acid soluble fraction (AS-P). This acid soluble fraction was further characterized as phytic acid phosphorus (PA-P), inorganic phosphorus (Pi) and the remaining acid soluble fraction (Po) which appeared to consist largely of nucleoside- and sugar phosphates.

RESULTS AND DISCUSSION

Comparison of Phosphorus-containing Components in Cultivated and Wild Oats

Preliminary analyses carried out on dry matrue primary caryopses of Sioux and a number of wild oat lines indicated definitie correlation of certain of the acid-soluble components with dormancy level. Differences did exist in the other fractions, but these were not related to the dormancy of the lines analyzed. Wild oat caryopses are smaller than caryopses of cultivated oats, and vary between lines. Relationships are presented on both a dry weight and a caryopsis basis in Table 1. The most interesting aspect of Table 1 is the negative correlation between Pi content and dormancy level among the dormant lines. This aspect has been repeatedly found in our experimental work (Jain _et al_., 1982, 1983: Quick _et al_., 1982/83). Regardless of nutrition or environmental history, the dormant lines maintain the same relative order of Pi content and are invariably much lower in Pi content than nondormant lines grown under similar conditions. PA-P, in spite of its abundance, was not obviously related to the dormancy level of the lines. The same was true of Po, at least in the dry, mature caryopses.

Table 1 Acid-soluble phosphorus components in dry primary caryopses of six lines of wild oats

	MON 73	Idaho	AN 474	AN 51	SH 319	SH 430
			μg P/g dry weight			
AS-P	4470cd^{+}	3975e	4580c	4324d	4755b	4986a
PA-P	3232cd	3275d	4012a	3605bc	3670bc	4057a
Pi	212d	210d	314c	329c	709a	535b
Po*	726	489	254	390	377	394
Total P	5842	5453	444	5737	6453	5888
			μg P/caryopsis			
AS-P	64.8d	60.0e	88.8a	62.7d	75.1c	83.3b
PA-P	46.9d	49.6d	77.8a	52.3d	5.0c	67.4b
Pi	3.1f	3.2ef	6.1c	4.8d	11.2a	8.9b
Po	10.5	7.4	4.9	5.7	6.0	6.6
Total P	84.7	82.3	105.6	83.2	102.0	98.3
Caryopsis wt. (mg)	14.5	15.1	19.4	14.5	15.8	16.7

$^{+}$Different letters in horizontal rows denote a difference significant at the 5% level.

*Derived by difference and not tested for significance.

Effect of Phosphorus Nutrition Supplied to Parental Plants on Dormancy of the Resulting Caryopses

If an association did exist between seed dormancy and Pi content, a change in one should produce a change in the other. Lower Pi levels and lower germination potential, i.e. deeper dormancy, coincided for all dormant lines of wild oat studied (Tables 2 and 3). Caryopses of wild oat lines competed more successfully for phosphorus under low phosphorus nutrient supply than was the case with the cultivar Sioux. The lower levels of Pi present in caryopses from phosphorus-stressed SH 319 plants did not lower the germination rate of this nondormant line. This may be related to the availability to the embryo of what Pi is present. Preliminary studies with extended levels of phosphorus suggest that a threshold level of phosphorus exists, above which changes in availabel phosphorus have little effect on the embryo response.

A significant reduction in germination and an extended period of time required for 50% germination to be attained, was found for all dormant lines subjected to phosphorus stress during seed maturation (Table 3). In the case of AN 51 a difference significant at the 5% level was evident by day 11, the first day after

Table 2 Influence of the phosphorus nutrient level given to parental plants on the total P and Pi present in mature primary caryopses of lines differing in dormancy level

Seed line	P level suppied (x 10^{-4}M)	Weight of caryopsis (mg)	P total (µg P/g d wt)	Pi (µg Pi/g d wt)
A. fatua				
Idaho	10.0	15.3	5001cde+	98fgh
	2.5	13.3	4847de	71gh
AN 474	10.0	18.8	5446ab	147de
	2.5	18.1	4270f	105fgh
AN 51	10.0	13.7	5639a	211c
	2.5	12.9	4832de	110efg
SH 319	10.0	14.8	5417ab	244bc
	2.5	14.5	4162f	117ef
A. sativa				
Sioux	10.0	31.2	4729e	510a
	2.5	28.7	3103g	261b

+Different letters indicate a difference significant at the 5% level.

Table 3 Cumulative percentage germination of caryopses from five lines of wild and cultivated oats, matured under high and low phosphorus nutrient levels

Avena line	P level applied (x 10^{-4}M)	Percentage germination at day							
		1	10*	11	12	17	21	28	$t_{1/2}$+
Idaho	10.0	0c**	2cd	2c	4d	78b	100a	100a	15.3
	2.5	0c	0d	0c	0d	8c	18c	76b	24.6
AN 474	10.0	0c	14c	18b	42b	100a	100a	100a	12.4
	2.5	0c	12c	12b	16cd	72b	90b	99a	14.4
AN 51	10.0	0c	13c	16b	28bc	96a	100a	100a	12.7
	2.5	0c	5cd	8bc	16cd	99a	100a	100a	13.5
SH 319	10.0	8b	87b	97a	99a	99a	100a	100a	1.7
	2.5	10b	90ab	99a	99a	99a	99a	99a	1.7
Sioux	10.0	100a	100a	100a	100a	100a	100a	100a	<1.0
	2.5	100a	100a	100a	100a	100a	100a	100a	<1.0

+$t_{1/2}$ is the time in days to produce 50% germination.

*At day 10 ungerminated caryopses were pierced through the middle with a dissecting needle.

**Different letters in the vertical rows indicate a difference significant at the 1% level.

piercing treatment (Quick et al., 1982/83). The $t_{1/2}$ was modestly extended in the phosphorus-stressed AN 51 caryopses following piercing. In all other dormant wild oat lines highly significant correlations were found between Pi level and dormancy. The germination of the nondormant SH 319 and the Sioux caryopses were not affected by the differences in phosphorus nutrition used in this experiment.

Effect of Water Imbibition on Phosphorus Fractions in Caryopses

Germination of wild oats, even in nondormant lines, is an uneven process with considerable variability possible (Table 3). In the cultivar Sioux, germination is very uniform, and an initial study of the period from start of imbibition to coleorhiza protrusion was made on this cultivar to establish trends in phosphorus transformations (Table 4). Of greatest interest was the decline in Pi that occurred over the initial hours of imbibition. A similar decline in wild oats at 24 hours of imbibition has been noted (Kovacs and Simpson, 1975). The massive reserves of PA-P were not called on until germination, as indicated by coleorhiza protrusion, neared completion. The subsequent degradation of PA-P undoubtedly accounted for the large increases in Pi reported in later stages of seedling development in oats (Hall and Hodges, 1966) and observed by us in wild oats (unpublished data). Increase

Table 4 Changes in Pi, PA-P, Po and germination in dehulled caryopses of A. sativa var Sioux during the initial 18 h of water imbibition. Phosphorus as micrograms per g dry wt

Period of imbibition (h)	Pi	PA-P	Po	% Germination
0	365a+	2512a	252d	0.0d
4	318ab	2515a	271cd	0.0d
12	277c	2513a	389ab	1.5d
13.5	284c	2510a	385ab	31.5c
14.5	288bc	2441b	502a	54.2b
18	286bc	2398b	552a	98.0a

+Within each vertical line the differences are significant at 5% level when different letters are present.

in the Po fraction was apparent early and became significant at the 5% level by 12 hours in Sioux oats (Table 4).

Drops in Pi were evident over the first 24 hours in SH 430 accompanied by increases in Po. However, since germination was only 14% at that point, phosphorus changes were difficult to interpret. An attempt to obtain some degree of synchronization was made. Caryopses of SH 430 imbibed 24 hours were arranged into groups with percentage germination corresponding to the levels shown in Table 4, and these selected groupings were checked for phosphorus changes in the acid soluable fraction (Table 5). Germination in this case has proceeded for 24 hours rather than 18 hours as with Sioux (Table 4) and some breakdown of PA-P was apparent, which obscured the initial Pi decline. However, by 24 hours the recovery of Pi levels was already becoming evident in the fully germinated grouping. No essential differences appeared to exist between Sioux and nondormant wild oat caryopses during the initial hours of germination.

Table 5 Changes in Pi, PA-P and Po in caryopses of SH 430 imbibed 24 h and grouped into known germination percentages

Component analyzed	Dry seeds	percent caryopses germinated				
		0	10	30	50	100
Pi	432a+	432a	345d	392bc	387bc	403b
PA-P	4108a	4037ab	3941bc	3902bc	3886c	3800c
Po	383b	449b	589a	594a	560a	640a

+Different letters in horizontal rows represent changes significant at the 5% level.

A different phosphorus pattern was apparent in dormant wild oat lines during imbibition (Table 6). Essentially no germination occurred over 10 days of imbibition. Germination could be induced in AN 474 and AN 51 by piercing the ten-day imbibed seeds, but Idaho and MON 73 required piercing and incubation in GA_3 to attain good germination. Incubation alone resulted in small declines in Pi in the two most dormant lines; more pronounced drops in the less dormant lines. No significant changes in PA-P occurred in any of the lines on imbibition over ten days. Piercing, followed by two days of water incubation (treatment 1), produced small, non-significant increases in all lines. No change was evident in PA-P levels, and only slight increases in Po levels. Incubation in GA_3 following piercing (treatment 2) produced effects comparable to those in germinating nondormant lines, with incresed Pi and lowered PA-P levels.

Table 6 The effects of incubation, piercing and GA_3 treatment on the acid soluble phosphorus components of wild oat caryopses of dormant lines (μg P/g d wt)

Line		Dry seed	Incubated 10 days	Treatment[+] 1	Treatment[+] 2
MON 73	Pi	212b[*]	188b	211b	350a
	PA-P	3532a	3557a	3533a	3391b
	Po	726	846	915	966
	Germination	0%	0%	0%	5.5%
Idaho	Pi	210b	179b	211b	347a
	PA-P	3275a	3288a	3279a	3182a
	Po	489	506	573	496
	Germination	0%	0%	0.5%	11.5%
AN 474	Pi	314b	169c	187c	440a
	PA-P	4012a	4033a	3997a	3743a
	Po	254	425	544	545
	Germination	0%	0.5%	0.5%	70.0%
AN 51	Pi	329b	193c	212c	440a
	PA-P	3605a	3575a	3582a	3287b
	Po	390	655	695	683
	Germination	0%	0.5%	0.5%	99.5%

[+] Treatment 1 = 10 d incubation in water, followed by piercing and 2 additional d water incubation. Treatment 2 = 10 d incubation in water followed by piercing and 2 d incubation in 5×10^{-4}M GA_3.

[*] Different letters in horizontal rows indicate differences significant at the 5% level.

ATP Synthesis during Imbibition of Wild Oat Caryopses

Germination appeared to require a large uptake of Pi in the caryopsis. The smaller drops in Pi associated with imbibition in dormant caryopses were probably associated with ATP synthesis. Studies with other species (Perl, 1980, 1980/81) suggest that ATP synthesis during the relatively anaerobic condition of early water imbibition is closely associated with the availability of Pi, AMP and PEP at the synthetic sites. ATP is produced during the initial hours of water imbibition in crop species lacking dormancy (Anderson, 1977; Moreland *et al*., 1974; Oberdorf and Marcus, 1974; Rodaway *et. al*., 1979). Since energy charge might be a factor associated with dormancy levels, we determined actual ATP levels and ATP synthesizing capacity in a number of wild oat lines (Table 7). Levels of ATP were low in comparison with those present in imbibed seeds (Jain *et al*., 1983). There was a statistically significant tendency for lower levels of ATP in strongly dormant lines, but no difference in ability to synthesize ATP, regardless of dormancy characteristics.

Accumulation of ATP was rapid in both dormant and nondormant seeds upon imbibition (Jain *et al*., 1983). Within two hours levels of ATP were 75 to 80-fold higher than in dry seeds, although absolute levels of ATP lagged behind in MON 73. However, in MON 73 the ATP levels continued to rise when synthetic activities in the less dormant lines had begun to deplete the ATP reserves. Only after some days did ATP levels drop in MON 73, suggesting a limited use of ATP in turnover activities not associated with germination (Cuming and Osborne, 1978b). The

Table 7 Pi, ATP and ATP synthetic capacity in dry mature *Avena* caryopsis

Avena species	Pi nmoles/mg	ATP pmoles/mg	ATP synthetic capacity pmoles/min/mg
A. fatua[+]			
MON 73	2.41d*	0.88e	71.3a
Idaho	2.30d	0.84e	75.2a
AN 474	3.38cd	0.81de	78.0a
AN 51	3.56c	0.90de	71.0a
CS 40	3.60c	1.00cd	68.3a
SH 319	3.78c	1.07bc	78.0a
SH 430	5.64b	1.19b	71.7a
A. sativa			
Sioux	10.45a	1.36a	71.9a

[+] *A. fatua* lines arranged in order of decreasing primary dormancy.
*Different letters in the vertical columns indicate a difference significant at 5% level.

enzymatic ability to from ATP was far in excess of ATP formed, indicating that any one of the phosphorylated compounds involved might be limiting (Jain *et al*., 1983).

Phosphorus Distribution in the Developing Wild Oat Caryopis

Caryopses of CS 40 were taken from the upper third of the panicle at 20 days and 40 days after anthesis. At 20 days seeds germinated readily, and by 40 days dormancy had been imposed. Plants were grown in controlled environment chambers under constant nutritional conditions. The only components to exhibit major changes were the Pi and PA-P fractions (Table 8). The Pi fraction was originally high and diminished to one-third of its former value by maturity. The Po did not change appreciably over this period. The imbibition data suggests that Pi levels do influence the germination process. Caryopses harvested 20 days after anthesis germinated, with a simultaneous uptake of Pi. The caryopses harvested 40 days after anthesis were dormant, the Pi levels were low, and imbibition did not cause any significant changes in Pi content.

A positional effect was studied in a follow-up experiment (unpublished data). The pattern of spikelet maturity is known to be basipetal, although the spikelet, itself, shows acropetal maturity of caryopses (Raju and Ramaswamy, 1983). The gradients in Pi content closely followed maturation patterns. At 20 days after anthesis, primary caryopses of the upper third of the panicle had Pi levels of 500 μg Pi/g dry weight while values double that were present in the lower third of the panicle where caryopses were approximately 15 days after anthesis. By 40 days from anthesis, little difference was apparent, all parts of the panicle were ripe, and Pi values were around 200 μg Pi/g d wt caryopsis. Secondary caryopses harvested 20 days after anthesis of associated primary caryopses were uniformly higher in Pi content than were primary caryopses, but the situation reversed by maturity. This appeared to reflect the later initiation (two days) but more rapid maturation of the smaller secondary caryopses. The secondary

Table 8 Phosphorus content of caryopses harvested 20 d and 40 d after anthesis (μg P/caryopis)

Phosphorus fraction	20 day caryopses		40 day caryopses	
	imbibition+		imbibition	
	without	with	without	with
Pi	8.4*	3.3	3.1	3.7
PA-P	38.1	39.8	58.5	58.0
Po	12.8	19.2	12.8	11.6

+Imbibed in water 2 d; dehulled on day 1.
*Mean of duplicate samples of 50 primary caryopses.

caryopses abscised before the primary caryopses and were more dormant. The level of Pi present in a given caryopsis is this influenced, not only by genetic potential and nutrition, but also by the position of the caryopsis on the panicle.

Phosphorus Components within the Embryo of the Wild Oat

The availability of phosphorus components to the embryo may be more significant than the total levels in the caryopsis. Embryos, on a dry weight basis, are much richer in phosphorus than the caryopsis as a whole. Incomplete separations of embryonic axis and endosperm can provide misleading results, and much early work on phosphorus content of oat caryopsis is suspect because of this fact (Albaum and Umbreit, 1943; Hall and Hodges, 1966). The large size of the oat scutellum, its capacity for expansive growth on imbibition, and the tendency to develop submerged beneath the endosperm make clean separations difficult. Preliminary analyses carried out on entrie and de-embryonated caryopses suggest that the Pi content of the embryo bears the same relationship to dormancy as was found for the entire caryopsis. Values for mean embryo Pi range from a low of four μg for MON 73 to a high of 16 μg for SH 430. Preliminary studies with CS 40 caryopses indicate that a substantial amount of the ATP production accompanying imbibition and germination occurs in the embryo. The wild oat embryo, accounting for no more than 1-2% of total mass, may account for as much as 30-40% of the ATP synthesized during early imbibition. Such competition for Pi within the embryo may deplete reserves necessary for other processes in germination, such as synthesis ofpoly A^{+}RNA (Payne, 1977). Analyses of dormant and nondormant embryos grown under conditions of phosphorus deprivation will help establish this point, as will studies on possible phosphorus turnover during the process of afterripening. These studies are currently in progress.

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REFERENCES

Albaum, H.G., and W.W. Umbreit. 1943. Phosphorus transformations during the development of the oat embryo. Am. J. Bot. 30: 553-558.

Anderson, J.D. 1977. Adenylate metabolism of embryonic axes from deteriorated soybean seeds. Plant Physiol. 59: 610-614.

Cuming, A.C., and D. J. Osborne. 1978a. Membrane turnover in imbibed and dormant embryos of the wild oat *Avena fatua* L. I. Protein turnover and membrane replacement. Planta 139: 209-217.

Cuming, A.C., and D.J. Osborne. 1978b. Membraned turnover in imbibed and dormant embryos of the wild oat *Avena fatua* L. II. Phospholipid turnover and membrane replacement. Planta 139, 219-226.

Hall, J.R., and T.K. Hodges. 1966. Phosphorus metabolism of germinating oat seeds. Plant Physiol. 41: 1459-1464.

Jain, J.C., W. A. Quick, and A.I. Hsiao. 1982. Studies of acid-soluble phosphorus compounds in genetically pure lines of *Avena fatua* with different dormancy characteristics. Can. J. Bot. 60: 2099-2104.

Jain, J.C., W.A. Quick, and A.I. Hsiao. 1983. ATP synthesis during water imbibition in caryopses of genetically dormant and nondormant lines of wild oat (*Avena fatua* L.). J. Exptl. Bot. 34: 381-387.

Kovacs, M.I.P., and G.M. Simpson. 1976. Dormancy and enzyme levels in seeds of wild oats. Phytochem. 15: 455-458.

Mayer, A.M., and I. Marbach. 1981. Biochemistry of the transition from resting to germinating state in seeds, p. 95-136. *In* L. Reinhold, J.B. Harborne, and T. Swain (ed.) Progress in Phytochemistry, Vol. 7. Pergamon Press, Oxford.

Moreland, D.E., G.G. Hussey, C.R. Shriner, and F.S. Farmer. 1974. Adenosine phosohate in germinating radish (*Raphanus sativus* L.) seed. Plant Physiol. 54: 560-563.

Naylor, J.M., and P. Fedec. 1978. Dormancy studies in seeds of *Avena fatua*. 8. Genetic diversity affecting response to temperature. Can. J. Bot. 56: 2224-2229.

Obenforf, R.L., and A. Marcus. 1974. Rapid increase in adenosine triphosphate during early wheat embryo germination. Plant Physiol. 53: 779-781.

Payne, P.I. 1977. Synthesis of poly $(A)^+$RNA in embryos of rye during imbibition and early germination. Phytochem. 16: 431-434.

Perl, M. 1980. An ATP-synthesizing system in seeds. Planta 149: 1-6.

Perl, M. 1980/81. Enzyme activities involved in ATP syntheseis in seeds. Israel J. Bot. 29: 307-311.

Quick, W.A., A.I. Hsiao, and J.C. Jain. 1982/83. Endogenous inorganic phosphate in relation to seed dormancy and germination of wild oats. Plant Sci. Letters 28: 129-135.

Raju, M.V.S., and S.N. Ramaswamy. 1983. Studies on the inflorescence of wild oats (*Avena fatua*). Can. J. Bot. 61: 74-78.

Rodaway, S., B.F. Huang, and A. Marcus. 1979. Nucleotide metabolism and the germination of seed embryonic axes, p. 203-218. *In* I. Rubenstein, R.L. Phillips, C.E. Green, and B.G. Gegenbach (ed.) The Plant Seed, Development, Preservation and Germination. Academic Press, New York.

Sasaki, K., and F.A. Loewus. 1980. Metabolism of myo-(2-^{3}H) inositol and scyllo-(R-^{3}H)inositol in ripening wheat kernels. Plant Physiol. 66: 740-745.

Sutcliffe, J.F., and O.A. Baset. 1973. Control of hydrolysis of reserve materials in the endosperm of germinating oat (*Avena sativa* L.) grains. Plant Sci. Letters 1: 15-20.

Williams, S.G. 1970. The role of phytic acid in the wheat grain. Plant Physiol. 45: 376-381.

THE INDUCTION AND BREAKAGE OF SEED DORMANCY IN WILD OATS

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ABSTRACT

The induction of dormancy and mortality due to water immersion of the seeds was affected by genotypes of the seed populations, age of the seeds, and various wetting and drying cycles. The mortality of the seeds on the soil surface increased markedly when exposed to higher rates of freezing temperatures to reach -25°C. Over 98% of the seeds on the soil surface were dead after 6 months of wintering. The persistence of the seeds in the soil can be extended not only by deep burial but also by the dormancy characteristics of the seeds. No seedlings emerged from pots with seeds placed at 15 cm depth and kept fully saturated with water. Ten weeks after flooding treatments, only 5% of the seeds buried at 7.5 cm emerged, as compared to 26% of the seeds buried at 2.5 cm. Seedling emergence in the pots with flooding treatments depended on the burial depth, duration of flooding treatment and genotypes of the seed populations. Based on the results of this study and results in the literature, a new strategy is suggested for flooding before freezing up as a control for wild oats.

Seed dormancy in wild oat (Avena fatua L.) has been long regarded as the main survival mechanism for this weed species, as well as many other annual weed species (Osborne, 1981). The persistence of wild oats in our cultivated soils is primarily due to seed dormancy (Banting, 1962), and seeds can remain dormant but viable for at least seven years (Banting, 1966a). The dormancy in wild oat seeds has been reviewed quite extensively by Chancellor (1976), Simpson (1978), and Naylor (in press).

The mechanism of seed dormancy in wild oats has been studied for almost 70 years. Mechanisms have been proposed including lack of oxygen supply to the seed (Atwood, 1914; Johnson, 1935), hormones/inhibitors antagonism (Andrews and Simpson, 1969; Hay, 1962; Naylor and Simpson, 1961; Simpson, 1976; Taylor and Simpson, 1980), shift in metabolic pathways (Simmonds and Simpson, 1971, 1972; Upadhyaya et al., 1982), lack of water supply to the embryo (Hsiao et al., in press), or lack of phosphorus-containing compounds, especially inorganic phosphorus (Jain et al., 1982, 1983; Quick et al., 1982/83). The fact still remains that wild oat is one of the most serious problems affecting our cereal crops.

A new concept has been developed recently with the application of a chemical treatment to break dormancy or stimulate germination in order to deplete the weed seed bank from infested fields (Anonymous, 1976; Hsiao et al., 1981). The approach has been successful with a few parasitic weeds, using ethylene (Eplee, 1975), strigol and strigol analogues (Johnson et al., 1976). Sodium azide (Fay and Gorecki, 1978; Fay et al., 1980), ethylene (Adkins and Ross, 1981) and ethrel (Adkins and Ross, 1981) were investigated for wild oat control, but none of the chemicals has been proven effective in actual control programs as yet.

We report the effects of water immersion, flooding, freezing or overwintering in the soil or on the soil surface on the induction of dormancy and mortality, as well as the breakage of dormancy of wild oat seeds of genetically pure lines and natural populations. The results of this study lead us to initiate a new strategy that flooding before freezing up may be used as a control for wild oats. Three assumptions are made concerning wild oat seeds with fall flooding treatment: (i) Seeds which are nondormant may germinate before freezing up, and, whether they emerge or not, will be killed by the freezing temperatures; (ii) Seeds which are nondormant may enter secondary dormancy and delay their spring emergence by at least one week after crop emergence; and (iii) Seeds which are dormant in the fall will have their dormancy reinforced and their spring emergence will be delayed for at least one week after crop emergence.

EFFECT OF WATER IMMERSION

In certain environmental conditions secondary dormancy can be induced, both in genetically dormant seeds that have lost primary dormancy, and in nondormant seeds from genetically nondormant lines of wild oats. The most cited condition for the induction of secondary dormancy is an excessively wet situation, which involves restriction of the oxygen supply due to the presence of hulls and adhering water (Banting, 1966a, b; Hay, 1962; Hay and Cumming, 1959; Hsiao, 1979; Hsiao and Simpson, 1971; Lewis, 1961). Prolonged excess of moisture leads eventually to death and autolysis of the seed (Banting, 1966b; Lewis, 1961). Many of the seeds which were dormant at the end of the first summerfallow period afterripened, and grew by early June of the second consecutive summerfallow year (Banting, 1962). However, under the influence of either primary or secondary states of dormancy, wild oats seeds have been shown to survive under natural conditions for as long as seven years in our cultivated soils (Banting, 1966a).

Experiments were carried out in the laboratory using Petri dishes at 18°C on the effects of one day water immersion plus one day drying (1+1) cycles, one day water immersion plus six day drying (1+6) cycles, or continuous water immersion on the induction of dormancy and mortality of genetically pure lines or natural populations. Overall, dormancy and strong vigor in seeds afterripened one month kept most of the viable seeds dormant for 12 1+1 cycles for natural population, at least 6 1+6 cycles for Idaho, and 4 1+6 cycles for CS 40 (Tables 1 and 2). About 5 to 12% of seeds afterripened 15 years remained viable after 6 1+1 or 1+6 cycles. There is considerable genotypic variation in the induction of dormancy and mortality are affected by genotypes of the seed populations, age of the seeds, and wetting and drying treatments.

Table 1 Effect of 1 d water imersion plus 1 d drying cycles on the induction of dormancy of wild oat seeds. Seeds of natural populations were harvested in 1977 and 1962 representing 1 mo and 15 yr of afterripening respectively. ND, nondormant, seeds germinated within first 10 d of incubation on water. V, viability, seeds germinated within 10 d of incubation on water plus seeds germinating after dehulling, piercing, and an additional 11 d incubation.

Age of seeds	ND or V	No. of water immersion and drying cycles						
		0	1	2	3	6	9	12
		(% Germination ± SE)						
1 mo	ND	42±2	4±1	0	0	0	0	0
	V	97±3	93±6	93±1	97±1	98±1	87±5	78±2
15 yr	ND	87±3	68±3	42±4	16±2	0	0	0
	V	90±3	84±2	64±2	29±5	5±1	2±1	5±3

EFFECT OF FREEZING TEMPERATURES

Temperatures are too low for five months of the year in western Canada to permit appreciable germination of wild oat seeds. However, low temperatures and alternate freezing and thawing hasten the afterripening of dormant seeds (Bibbey, 1948; Chepil, 1946). Banting (1966a) found that only 3 to 5% of the seeds remained viable after the first winter. Bibbey (1948) also noted that wet conditions in the fall induced more seeds on the soil surface to germinate than in somewhat dry conditions. Seeds of natural populations were used in all of these studies.

Table 2 Effect of 1 d water immersion plus 6 d drying cycles on the induction of dormancy of genetically pure lines of wild oat seeds. Seeds of Idaho and CS 40 were harvested in 1978 representing 1 mo afterripening with Idaho harvested in 1962 representing 15 yr of afterripening. ND and V are the same as in Table 1.

Line	Age of seeds	ND or V	No. of water immersion and drying cycles						
			0	1	2	3	4	6	12
			-------------(% Germination ± SE----------						
Idaho	1 mo	ND	10±2	5±1	0	0	0	0	--
		V	99±1	99±1	99±1	98±1	99±1	99±1	--
	15 yr	ND	94±5	91±2	84±3	74±4	32±3	6±2	--
		V	94±5	95±3	99±1	79±3	51±2	12±5	--
CS 40	1 mo	ND	84±2	59±3	34±2	18±2	27±6	12±1	9±3
		V	100	100	100	98±1	91±4	52±4	27±2

Table 3 Effect of continuous water immersion on the induction of dormancy of wild oat seeds. Seeds of pure lines were harvested in 1980 representing 1 mo of afterripening. Seeds of natural population (NP) were collected in 1977 and stored at -20°C after 1 mo or 5 yr of afterripening. ND, nondormant, seed germinated within first 10 wk of incubation on water. V, viability, seeds germinated within 10 wk of incubation on water plus seeds germinating after dehulling, piercing, and additional wk of incubation.

Line	Age of seeds	Days of continuous water immersion									
		0		0		0		0		Mean	
		ND	V	ND	V	ND	V	ND	V	ND	V
		----------------(% Germination ± SE)------------									
SH 430	1 mo	90	95	46	97	30	95	25	96	48	96
SH319	1 mo	86	95	6	75	2	61	1	40	24	67
CS 40	1 mo	69	83	12	82	14	89	14	77	27	83
AN 51	1 mo	2	82	2	56	7	44	4	14	4	49
NP	1 mo	16	77	4	58	0	49	1	44	5	57
NP	5 yr	82	83	69	81	43	71	30	64	56	75
Mean		58	86	23	75	16	68	13	56		

	ND	V
LSD: individual lines and water immersions	9	20
LSD: means of lines	4	10
LSD: means of water immersions	4	8

(P = 0.05)

Seeds of CS 40, AN 51 and a natural population were placed in nylon screen bags. Bags were nailed to the soil surface in the field in November 1979. After six months of wintering on the soil surface, only 1.3% of the seeds remained viable regardless of their dormancy characteristics (Table 4).

Table 4 Effect of overwinter on the soil surface in the field for 6 mo on the germination and viability of wild oat seeds. Seeds of CS 40, AN 51 and one natural population (NP) were collected in 1979 from the surface of plots and were placed in nylon screen bags. ND and V are the same as in Table 1.

Line	November 22, 1979		May 23, 1980	
	ND	V	ND	V
	(% Germination ± SE)			
CS 40	7.2±1.4	92.0±2.5	0.0	1.3±0.5
AN 51	0.0	97.3±1.3	0.0	0.3±0.3
NP	1.3±0.8	89.3±2.3	0.0	1.3±0.4

The effect of varying the rate at which seeds are brought to, and returned from, -25°C was investigated by Dr. J. D. Banting in 1970 and the results are presented in Table 5. Small plastic containers with tight-fitting lids and Regina heavy soil were used. Seeds were placed on the soil surface with 40% moisture (DW) for 24 hours, at which time seeds had 33% moisture (DW). Containers were placed in freezing cabinets set to rates of 1 to 5°C/h to reach -25°C. After holding at -25°C for one hour, half of the containers were removed and placed in a refrigerator at 1 to 2°C for 12 hours to thaw (slow thaw). With the remaining containers the cabinet was warmed at the rate 2°C/h for 12 hours (quick thaw) One hour at -25°C attained by a freezing rate of 5°C/h resulted in 90% mortality of the seeds, regardless of whether slow or quick thaw was used (Table 5). A freezing rate of 3°C/h resulted in 75% mortality. Mortalities of 20 to 30% were obtained when freezing rate was reduced to 1°C/h, and in this case quick thaw appeared superior to slow thaw in retaining viability. It can be concluded that the mortality of the seeds on the soil surface may be affected by the combination of rate of freezing and thawing temperatures, duration of the freezing temperatures, and the moisture content of the soil and the seeds.

Table 5 Effect of different rates of freezing temperatures to reach -25°C on the survival of imbibed, unhardened wild oat seeds on the surface of the soil. Seeds of a natural population were harvested in 1966 and stored in a refrigerator until use (1970). After holding at -25°C for 1 h, half of the containers were removed and placed in a refrigerator at 1 to 2°C for 12 h to thaw (slow thaw). With the remaining containers the cabinet was warmed at the rate of 2°C/h for 12 h (quick thaw). Germination and viability tests of seeds without freezing treatment (controls) were carried out on soil surface or in Petri dishes. ND, nondormant, seeds germinated within the first 2 wk of incubation on water at 18°C. V, viability, seeds germinated after 2 wk plus seeds germinating after dehulling, piercing, and an additional 2 wk of incubation.

Rate of freezing	ND or V	Controls		Slow thaw	Quick thaw
		Petri dish	Soil surface		
(°C/h)		------------(% Germination ± SE)----------			
5	ND	87±1	87±2	0	0
	V	95±1	95±2	6±2	7±2
3	ND	90±2	79±3	11±3	11±3
	V	97±1	90±3	13±3	15±2
1	ND	88±3	82±3	44±6	56±4
	V	96±1	87±2	55±7	70±5

EFFECT OF DEPTH OF BURIAL

Although 60 to 80% of wild oat seedlings emerged from seeds occurring in the top 7.5 cm of the soil, some can come from as deep as 19 cm (Holroyd, 1964) or even 23 cm (Thurston, 1951), but the deeper the soil is buried the less the chance of its emerging.

Experiments on the effects of seed burial at various depths in the field on the germinated seedlings, viability and mortality of seeds of two pure lines were carried out for two years. Six replicates of 400 seeds each were placed at respective depths in the 25 cm diameter plastic pots and were buried in the field. Our results showed that germinated seedlings, viability and mortality were affected significantly by the burial depth (Table 6). Our results confirm the findings of Banting (1966a) that deep burial extended the period of persistence. Banting (1966a) found that of seeds of a natural population buried at 5, 10, and 15 cm only 1.5, 6.8 and 12.0% respectively remained viable after the first year, and 1.5, 5.2 and 4.2% respectively after the second year. Seeds of AN 51 are genetically more dormant than seeds of CS 40. Our results on

CS 40 at 5 cm depth were comparable to Banting's for both years. Under our conditions, viability of seeds of CS 40 buried at 10 and 15 cm were 19.2 and 53.6% respectively after the first year, and 0.58 and 5% respectively after the second year. In the case of AN 51, seeds at all burial depths had higher viability after one and two years than was found for CS 40 or for Banting's natural populations. The differences between our results and those obtained by Banting may be due to weather conditions and our use of genetically pure lines. Thus, the persistence of the seeds can be extended by wet conditions, burial depth and genetic potential of seed for dormancy.

Table 6 Effect of seed burial at various depths in the field on the germinated seedlings, viability and mortality of wild oats. Seeds were harvested in August 1980 and stored at -20°C until use (September 1980). Pots were brought into the laboratory in May 1981 (8 mo) and July 1982 (22 mo). The germinated seedlings and seeds were picked up by hand. Viability of the ungerminated seeds was established by the same procedures as in Table 1. The remaining seeds were considered dead. The number in the ( ) was SE.

Line	Burial depth	8 months			22 months		
		Germinated	Viability	Dead	Germinated	Viability	Dead
	(cm)	(%)					
CS40	5	93.58	1.00	5.42	0.00	0.04	99.96
		(2.68)	(0.29)	(2.64)		(0.04)	(0.04)
	10	80.71	19.21	0.08	0.04	0.58	99.04
		(3.69)	(3.79)	(0.05)	(0.04)	(0.29)	(0.56)
	15	45.79	53.63	0.58	4.83	5.00	90.17
		(13.13)	(13.71)	(0.21)	(2.32)	(1.48)	(2.81)
AN 51	5	78.17	10.50	11.33	1.63	1.33	97.04
		(4.93)	(2.03)	(4.63)	(0.47)	(0.29)	(0.51)
	10	61.54	38.46	0.00	17.71	36.37	45.92
		(6.87)	(6.95)		(4.67)	(8.40)	(5.41)
	15	19.79	80.08	0.13	23.92	27.13	48.95
		(11.13)	(11.50)	(0.09)	(8.50)	(8.71)	(9.44)

EFFECT OF FLOODING AND BURIAL DEPTH

No wild oat seeds germinated after being submerged for 6, 18 or 42 months in a fresh-water canal (Burns, 1965). Lewis (1961) found that no wild oat seeds survived in water-logged soils for 2 months.

In western Canada, the effect of flooding treatment on the emergence of wild oat seeds buried at various depths has not been investigated, either in the field or in the greenhouse. Four replicates of 50 seeds each of three pure lines were placed at three depths of sandy loam soil in 25 cm diameter plastic pots and were submerged for one to four days in the greenhouse. For the controls water was added from the top until it dripped from the bottom. Pots were then placed in wooden boxes containing 2.5 cm tap water. In this way, water was supplied only from the bottom and soil in pots remained fully saturated with water after flooding treatments. No seedling emerged over 7 months from the seeds buried at 15 cm regardless of flooding treatment and dormancy characteristics of the seeds (data not shown). These pots will be moved to the field for observing their seedling emergence during the 1983 crop season. Ten weeks after the flooding treatments, only 5% of the seeds buried at 7.5 cm emerged, as compared to 26% of the seeds at 2.5 cm burial depth (Table 7). Among seeds buried at 2.5 cm, more seedlings emerged of SH 340 and of CS 40 than of SH 319. More seedlings emerged from pots with one and two day flooding treatments than from four-day and control pots. The reason for the surprisingly low emergence in controls was not known. The results of this study indicated that emergence of seedlings is affected by the duration of flooding treatment, burial depth, and genotype of the seed populations.

DISCUSSION

Friesen and Shebeski (1960) found crop yield reductions ranging from 5 to 50% in fields in which wild oats was the dominant species. The longer the wild oat plants remained in the plots, the lower the crop yield (Bowden and Friesen, 1967). Friesen (1973) studied the effect of wild oat densities on crop yield reductions and found that for approximately 50 wild oat plants/m^2, loss in yield in wheat, barley, rapeseed and flax were 24, 16, 18 and 42% respectively. The degree of crop yield reduction also depended on whether the wild oats emerge before, at the same time, or after the crop. Hunter (1983) reported that at 50 wild oat plants/m^2, yield loss as compared to weed-free controls, due to wild oat plants emerged one week before, at the same time, and one week after the crop were 26, 10 and 7% respectively in wheat, and 63, 60 and 36% respectively in flax. Thus, the ideal treatment is to apply treatment(s) in order to delay or prevent the wild oat emergence for at least one week after the crop. This will reduce their competitive ability and consequently will reduce yield loss greatly.

Over 98% of the seeds on the soil surface were dead after 6 months of winter regardless of their dormancy characteristics (Table 4). Banting (1966a) and Bibbey (1948) also reported that over 95% of the seeds placed on the soil surface were dead the following spring. The flooding treatment given before freezing up should put all nondormant seeds under more critical conditions. Nondormant seeds present in the soil in the fall can either germinate and be killed by the freezing temperatures, or be induced to

Table 7 Greenhouse study of the effect of flooding duration and depth of seed placement on the emergence of 3 genetically pure lines of wild oats. Seed sources were the same as in Table 3. For the controls, water was added from the top until it dripped from the bottom. Pots were then placed in boxes containing 2.5 cm tap water. In this way, the soil was saturated with water supplied only from the bottom. Seedlings emerged were counted and clipped over a 10 wk period.

Line	Flooding	Depth of seed placement, cm			Mean
		2.5	7.5	15.0	
	(day)	(% Emergence)			
SH 430	0	8	7	0	5pf
	1	45	8	0	18pf
	2	58	8	0	22pf
	4	10	9	0	6pf
	Mean	30pd	8pd	0pd	13p
SH 319	0	10	2	0	4pf
	1	9	9	0	6pf
	2	25	5	0	10pf
	4	15	6	0	7pf
	Mean	15pd	6pd	0pd	7p
CS 40	0	7	1	0	3pf
	1	53	2	0	18pf
	2	39	2	0	14pf
	4	35	0	0	12pf
	Mean	34pd	1pd	0pd	12p
Mean	0	8fd	3fd	0fd	4f
	1	36fd	6fd	0fd	14f
	2	41fd	5fd	0fd	15f
	4	20fd	5fd	0fd	8f
Mean		26d	5d	0d	

LSD values at P = 0.05

Individual lines, flooding and seed placement	11
p = Means of lines	3
f = Means of flooding	4
d = Means of seed placement	3
pf = Means of lines and flooding	6
pd = Means of lines and seed placement	6
fd = Means of flooding and seed placement	6

become secondarily dormant due to wet condition. These results should give support to the first two assumptions of the new strategy mentioned in the Introduction. The flooding treatment before freezing up should also reinforce the dormancy in dormant seeds and extend their lengths of afterripening. Their emergence should be delayed for at least one week after the crop emergence. This should give support to the third assumption of the new strategy.

Thus, it is necessary to carry out further work under field conditions to determine if this flooding treatment would have practical value for killing wild oat seedlings before freezing up, and preventing or delaying their seedling emergence for at least one week after the crop in the following spring. Field work on the induction and breakage of dormancy by flooding treatment in the early spring is in progress in small plots at the Regina Research Station. By using irrigation facilities, larger plots will also be established in the late fall of 1983 in Mr. N. Martin's farm in Broadview, Saskatchewan, to validate our new strategy.

REFERENCES

Adkins, S. W., and J. Ross. 1981. Studies in wild oat seed dormancy. I. The role of ethylene in dormancy breakage and germination of wild oat seeds. Plant Physiol. 67:358-362.

Andrews, C. J., and G. M. Simpson. 1969. Dormancy studies in seed of Avena fatua. 6. Germinability of the immature caryopsis. Can. J. Bot. 47:1841-1849.

Anonymous. 1976. Pest control: An assessment of present and alternative technologies, p. 143. In Corn/Soybeans Pest Control. Vol. 2. Nat. Acad. Sci., Nat. Res. Counc. Environ. Stud. Bd., U.S.A.

Atwood, W. M. 1914. A physiological study of the germination of Avena fatua. Bot. Gaz. 57:386-414.

Banting, J. D. 1962. The dormancy behaviour of Avena fatua L. in cultivated soil. Can. J. Plant Sci. 42:22-39.

Banting, J. D. 1966a. Studies on the persistence of Avena fatua. Can. J. Plant Sci. 46:469-478.

Banting, J. D. 1966b. Factors affecting the persistence of Avena fatua. Can. J. Plant Sci. 46:469-478.

Bibbey, R. O. 1948. Physiological studies of weed seed germination. Plant Physiol. 23:467-484.

Bowden, B. A., and G. Friesen. 1967. Competition of wild oats (Avena fatua L.) in wheat and flax. Weed Res. 7:349-359.

Burns, V. F. 1965. The effects of fresh water storage on the germination of certain weed seeds. Weeds 13:38-39.

Chancellor, R. J. 1976. Seed behaviour, p. 65-87. In D. P. Jones (ed.) Wild Oats in World Agriculture. Agr. Res. Counc., London.

Chepil, W. S. 1946. Germination of weed seeds. I. Longevity, periodicity of germination, and vitality of seeds in cultivated soils. Sci. Agr. 26:307-346.

Eplee, R. E. 1975. Ethylene: A witch weed seed germination stimulant. Weed Sci. 23:433-436.

Fay, P. K., and R. S. Gorecki. 1978. Stimulating germination of dormant wild oat (Avena fatua) seed with sodium azide. Weed Sci. 26:323-326.

Fay, P. K., R. S. Gorecki, and P. M. Fuerst. 1980. Coating sodium azide granules to enhance seed germination. Weed Sci. 28:674-677.

Friesen, G., and L. H. Shebeski. 1960. Economic losses caused by weed competition in Manitoba grain fields. I. Weed species, their relative abundance and their effect on crop yields. Can. J. Plant Sci. 40:457-467.

Friesen, H. A. 1973. Identifying wild oat yield losses and assessing cultural control methods, p. 20-25. In Seminar - Let's Clean up on Wild Oats. Agr. Can. and U.G.G. Ltd., Saskatoon, SK.

Hay, J. R. 1962. Experiments on the mechanism of induced dormancy in wild oats (Avena fatua L.). Can. J. Bot. 40:191-202.

Hay, J. R., and B. G. Cumming. 1959. A method for inducing dormancy in wild oats (Avena fatua L.). Weeds 7:34-40.

Holroyd, J. 1964. The emergence and growth of Avena fatua from depths in the soil. Brit. Weed Contr. Conf. Proc., 7:621-627.

Hsiao, A. I. 1979. The effect of sodium hypochlorite and gibberellic acid on seed dormancy and germination of wild oats (Avena fatua). Can. J. Bot. 57:1729-1734.

Hsiao, A. I., and G. M. Simpson. 1971. Dormancy studies in seed of Avena fatua. 7. The effects of light and variation in water regime on germination. Can. J. Bot. 49:1347-1357.

Hsiao, A. I., G. I. McIntyre, and J. A. Hsiao. (In press). Seed dormancy in Avena fatua. I. Induction of germination by mechanical injury. Bot. Gaz. 144.

Hsiao, A. I., A. D. Worsham, and D. E. Moreland. 1981. Effects of sodium hypochlorite and certain growth regulators on germination of witch weed (Striga asiatica) seeds. Weed Sci. 29:98-100.

Hunter, J. H. 1983. Cultural control methods for wild oats, p. 43-52. In Wild Oat Symposium '83. Canadian Plains Research Center, Regina, SK.

Jain, J. C., W. A. Quick, and A. I. Hsiao. 1982. Studies of acid-soluble phosphorus compounds in genetically pure lines of Avena fatua with different dormancy characteristics. Can. J. Bot. 60:2009-2014.

Jain, J. C., W. A. Quick, and A. I. Hsiao. 1983. ATP synthesis during water imbibition in caryopses of genetically dormant and nondormant lines of wild oat (Avena fatua L.). J. Exptl. Bot. 34:381-387.

Johnson, A. W., G. Rosebery, and C. Parker. 1976. A novel approach to Striga and Orobanche control using synthetic stimulants. Weed Res. 16:223-227.

Johnson, L. P. V. 1935. General preliminary studies on the physiology of delayed germination in Avena fatua. Can. J. Res. C. 13:283-300.

Lewis, J. 1961. The influence of water level, soil depth and type on the survival of crop and weed seeds. Int. Seed Test Assoc. Proc. 26:68-85.

Naylor, J. M. (In press). Genetic studies on the control of some physiological processes in seeds. Can. J. Bot.

Naylor, J. M., and G. M. Simpson. 1961. Dormancy studies in seed of Avena fatua. 2. A gibberelllin-sensitive inhibitory mechanism in the embryo. Can. J. Bot. 39:281-295.

Osborne, D. J. 1981. Dormancy as a survival strategem. Ann. Appl. Biol. 98:525-531.

Quick, W. A., A. I. Hsiao, and J. C. Jain. 1982/83. Endogenous inorganic phosphate in relation to seed dormancy and germination of wild oats. Plant Sci. Letters 28:129-135.

Simmonds, J. A., and G. M. Simpson. 1971. Increased participation of pentose phosphate pathway in response to afterripening and gibberellic acid treatment in caryopses of Avena fatua. Can. J. Bot. 49:1833-1840.

Simmonds, J. A., and G. M. Simpson. 1972. Regulation of the Krebs cycle and pentose phosphate pathway activities in the control of dormancy of Avena fatua. Can. J. Bot. 50:1041-1048.

Simpson, G. M. 1966. The suppression by (2-chloroethyl)trimethyl ammonium chloride of synthesis of gibberellin-like substance by embryos of *Avena fatua*. Can. J. Bot. 44:115-116.

Simpson, G. M. 1978. Metabolic regulation of dormancy in seeds - a case history of the wild oat (*Avena fatua*), p. 167-200. In M. E. Clutter (ed.) *Dormancy and Development Arrest*. Academic Press, New York, NY.

Taylor, J. S., and G. M. Simpson. 1980. Endogenous hormones in afterripening wild oat (*Avena fatua*) seed. Can. J. Bot. 58:1016-1024.

Thurston, J. M. 1951. Some experiments and field observations on the germination of wild oat (*Avena fatua* and *A. ludoviciana*) seed in soil and the emergence *of seedlings*. *Ann. Appl.* Biol. 38:812-832.

Upadhyaya, M. K., J. M. Naylor, and G. M. Simpson. 1982. The physiological basis of seed dormancy in *Avena fatua* L. I. Action of the respiratory inhibitors sodium a*zide and s*alicylhydroxanic acid. Physiol Plant. 54:419-424.

THE ROLE OF WATER IN THE MECHANISM OF SEED DORMANCY IN WILD OATS (AVENA FATUA L.)

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ABSTRACT

A study was conducted under controlled conditions of factors affecting the uptake and distribution of water in the dormant caryopsis of wild oats. The decrease in water content of the caryposis during maturation was correlated with a rapid increase in dormancy. The mature but dormant caryopsis absorbed water readily, the water content of the embryo and of the surrounding tissues reaching almost constant values (% D.W.) of 125% and 65% respectively after 10 days of imbibition. Induction of germination by piercing the seed coat of the imbibed caryopsis was not prevented by covering the hole with lanolin and was significantly accelerated by the application of water. The water content of the embryo increased significantly within 24 hours of the piercing treatment, and more than 6 hours prior to germination. The embryo, when excised from the imbibed caryopsis and supplied with water, showed a similar but more rapid response. These results are consistent with the hypothesis that seed dormancy in wild oats is due primarily to factors which prevent the imbibed water from being taken up by the embryo in the amount required to trigger the onset of germination. Some of the factors which may be involved in this mechanism are briefly discussed.

INTRODUCTION

Early studies on factors affecting the germination of wild oats (*Avena fatua* L.) showed that the dehulled caryopsis absorbed water readily, the rate of imbibition exceeding that of the cultivated oat (*Avena sativa*) and of several other cereals with non-dormant seeds (Atwood, 1914). It was, therefore, concluded that the dormancy of the wild oat seed could not be attributed to any restriction in the uptake of water. Similar observations on the imbibition of water by the dormant seeds of various other species have led to the same conclusion (Crocker, 1906; Ikuma and Thimann, 1963). However, a recent study of the effect of mechanical injury on the germination of wild oats (Hsiao *et al.*, in press), suggested that the dormancy of the imbibed caryopsis may be due, at least partly, to factors which prevent the uptake of the imbibed water by the embryo in the amount required to trigger the onset of germination. Since the role of water in the mechanism of seed dormancy in wild oats has received very little attention (reviewed by Simpson, 1978) it was decided to initiate a comprehensive study of the water relations of the wild oat, with particular reference to the influence of the water supply on the development and dormancy of the seed. Results obtained in the initial phase of this investigation are summarized and briefly discussed in the present report.

MATERIALS AND METHODS

All experiments were conducted with a strain of wild oats (CS 40) isolated from a natural population on the farm of the Department of Crop Science, University of Saskatchewan, Saskatoon (Naylor and Jana, 1976). In comparative studies under controlled conditions this strain was reported to have a relatively low level of dormancy (Jana et al., 1979). However, under the conditions of the present investigation, seeds which had not germinated after 10 days of imbibition at 20±1° (usually 70 to 80%) remained dormant for at least 12 weeks.

All plants were grown under controlled conditions and watered with a modified Hoagland's solution as previously described (Hsiao et al., in press). Only mature, primary seeds were used and were stored at -15° until required for experimental treatment.

EXPERIMENTAL RESULTS

Correlated Changes in the Water Content and Dormancy of the Seed During Maturation

A study was conducted to determine the changes which occur in the water content of the caryopsis during its growth and maturation on the parent plant, and to relate these changes to the degree of dormancy of the seeds. All seed samples were taken from branches arising from the basal node of the inflorescence and were collected at various times after anthesis.

The total water content of the caryopsis increased by 30% between 7 and 14 days after anthesis (Fig. 1A). It remained relatively constant for the following 10 days and then, during a brief period between 27 and 30 days from anthesis, it decreased rapidly by approximately 60%. Since the initial phase of water uptake was accompanied by an almost fourfold increase in dry weight (data not shown), the water content during this period declined markedly when expressed on a dry weight basis. The ratio of water to dry weight continued to decline throughout most of the sampling

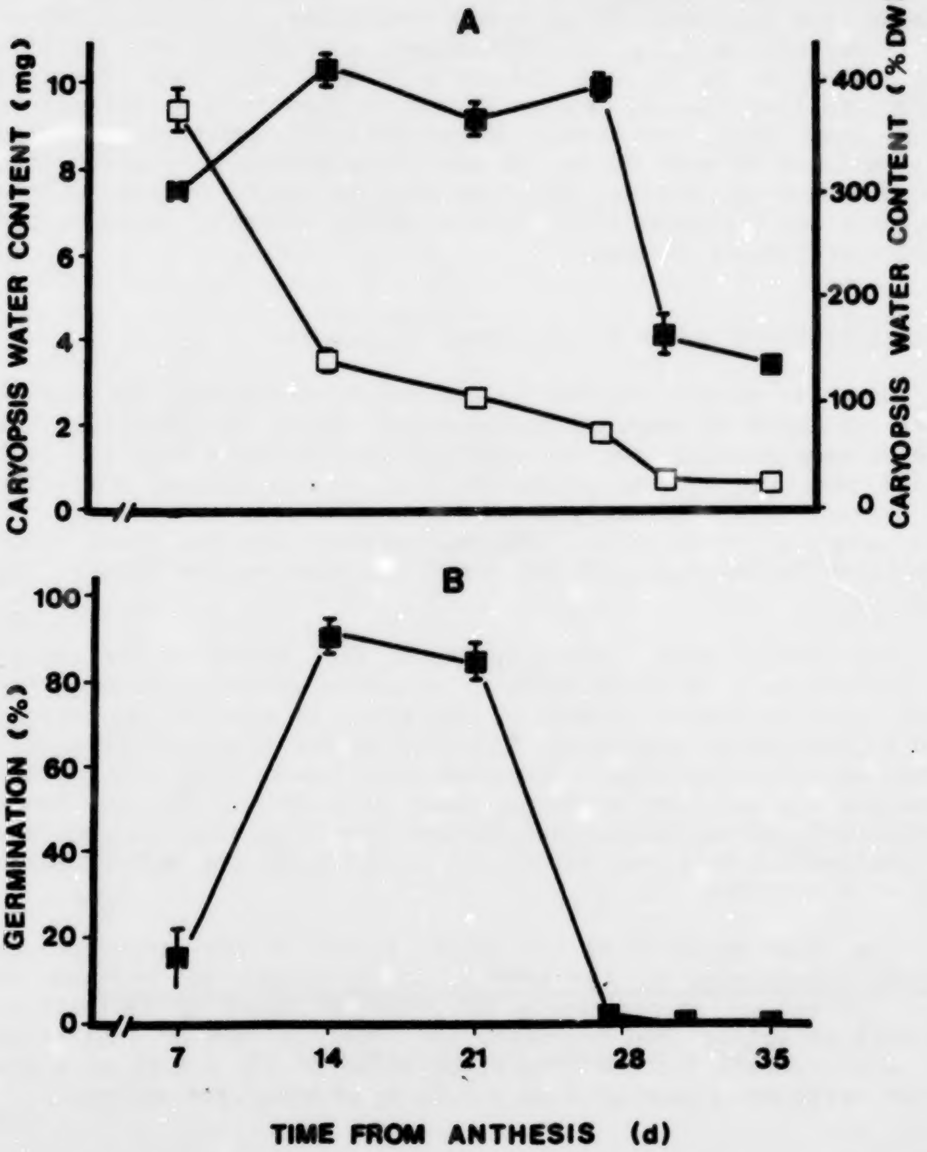

Fig. 1 Changes in (A) water content and (B) % germination of the wild oat caryopsis during its growth and maturation on the parent plant. The water content is expressed both as weight of water per caryopsis (■) and as % D.W. (□). All data are means of 10 replicates per sample. Standard errors of the means are indicated by vertical lines.

period, falling from a maximum of 370% after 7 days from anthesis to a minimum value of 18.5% at maturity.

During the initial phase of water uptake germination increased from less than 20% at 7 days from anthesis to almost 90% in the 14 day samples (Fig. 1B). It showed a slight but not significant reduction during the following 7 days and then decreased rapidly to less than 5% between 21 and 28 days from anthesis. It is intended that, in further investigations, additional samples will be taken between 20 and 30 days from anthesis in order that the relationship between the reduction in water content of the caryopsis and the associated increase in the degree of dormancy can be more critically assessed.

The Imbibition of Water by the Dormant Caryopsis

Water is readily imbibed by the mature caryopsis. In experiments conducted to measure the rate and amount of imbibition the embryos were excised, and the water content of the embryo and that of the remainder of the caryopsis, i.e. of the tissues enclosing the embryo, were separately determined. The mean values recorded were based on seeds which remained dormant; the few seeds which germinated in the course of the experiment were not included in the data.

The rate of water uptake by the tissues enclosing the embryo was curvilinear, the water content increasing gradually from an initial value of 12% to a mean of 65% after 10 days of imbibition, with a total water content of 11.1 ±0.4 mg per caryopsis (Fig. 2). There was evidence from subsequent experiments that the intact caryopsis may continue to imbibe water at a decreasing rate for a considerably longer period, but further investigations are required to substantiate this observation and to determine the maximum duration of imbibition.

The water absorbed by the outer tissues of the caryopsis was rapidly transported to the embryo, which showed an increase in water content of approximately 65% after 24 hours of imbibition. The rate of uptake then decreased and after 10 days of imbibition the water content reached a constant value of 124 ± 4.6% on a dry weight basis and a mean of 0.84 ± 0.03 mg of water per embryo.

Induction of Germination by Mechanical Injury or Isolation of the Embryo

a) Effect of Piercing the Seed Coat. It has been reported by several investigators that the dormancy of wild oat seeds can be broken by piercing a hole in the imbibed caryopsis (Atwood, 1914; Hay, 1962; Hsaio, 1979). There is no agreement, however, as to the nature of the mechanism involved. In a recent study of the germin-

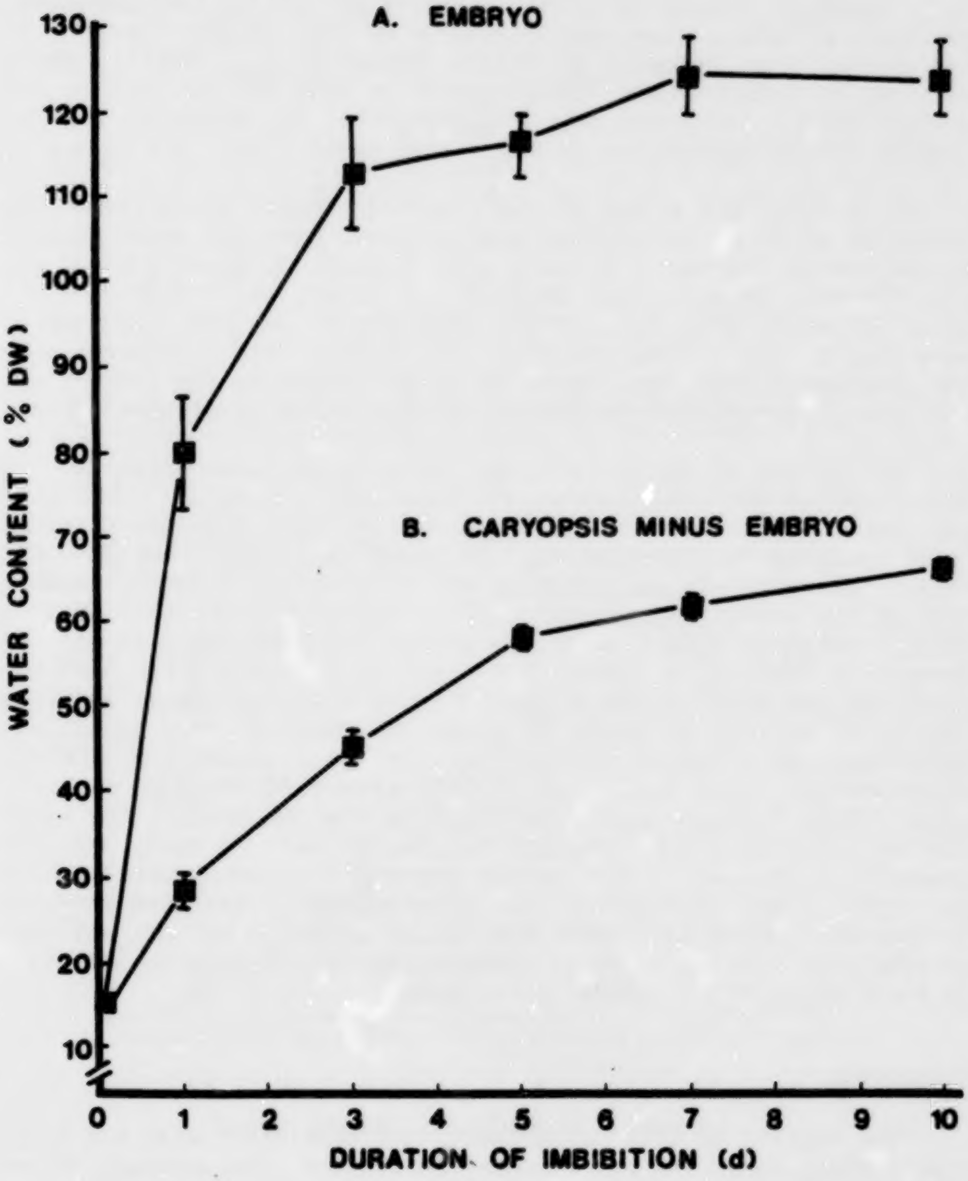

Fig. 2 The uptake of water by (A) the embryo and (B) by the enclosing tissues of the caryopsis during inbibition in the dark at 20 ± 1°C. All data are means of 10 replicates per sample. Standard errors of the means are indicated by vertical lines.

ation response induced by either piercing or cutting the caryopsis, the rate of germination was inversely related to the distance of the embryo from the site of injury (Hsiao et al., 1983). While germination induction was not prevented by covering the hole or cut surface with lanolin the rate of germination was significantly increased by the application of wet filter paper (Figs. 3A, B).

A study of the effect of piercing the imbibed caryopsis on the uptake of water by the dormant embryo showed that the water content of the embryo increased markedly with 6 hours of treatment and was significantly greater than that of the intact control ($P < 0.05$) after 24 hours (Fig. 4). Since germination did not begin until more than 30 hours after piercing, the results were consistent with the hypothesis that the increased water uptake by the embryo was the cause, rather than the effect, of the induction of germination.

b) Effect of Embryo Excision. A study of water uptake by excised embryos provided further evidence that the water content of the embryo of the imbibed caryopsis may be lower than the critical level required for germination. In these experiments the dormant, intact caryopsis was permitted to imbibe water until the water content of the embryo had reached a constant value (Fig. 5). At this point, the water potential of the embryo was presumably in equilibrium with that of the adjacent tissues of the caryopsis. The excised embryos were then transferred to moist filter paper and were thus provided with a supply of water at close to zero potential. Subsequent measurements showed that the water content of the excised embryos increased by 22 ± 0.5% within 30 minutes of excision. This increase was significant at the 5% level. The water content remained almost constant for the following 6 hours and then gradually increased. This second phase of increased water uptake can probably be attributed to the water potential gradient produced by the stimulation of growth and solute accumulation and was correlated with the beginning of germination, which reached 50% after 24 hours and 100% in the 36-hour samples.

DISCUSSION

The results of these experiments are consistent with the hypothesis that, under the experimental conditions, the dormancy of the intact caryopsis was due primarily to the failure of the imbibed water to be taken up by the embryo in the amount required for the induction of germination. Evidence that water was the limiting factor was provided, firstly, by the increased germination response to mechanical injury which resulted from the application of water to the hole or cut surface (Fig. 3); and secondly, by the rapid increase in the water content of the embryo induced by the piercing and excision treatments, and which was clearly distinct from the subsequent increase associated with germination (Figs. 4 and 5).

In seeking an alternative explanation for these results, it

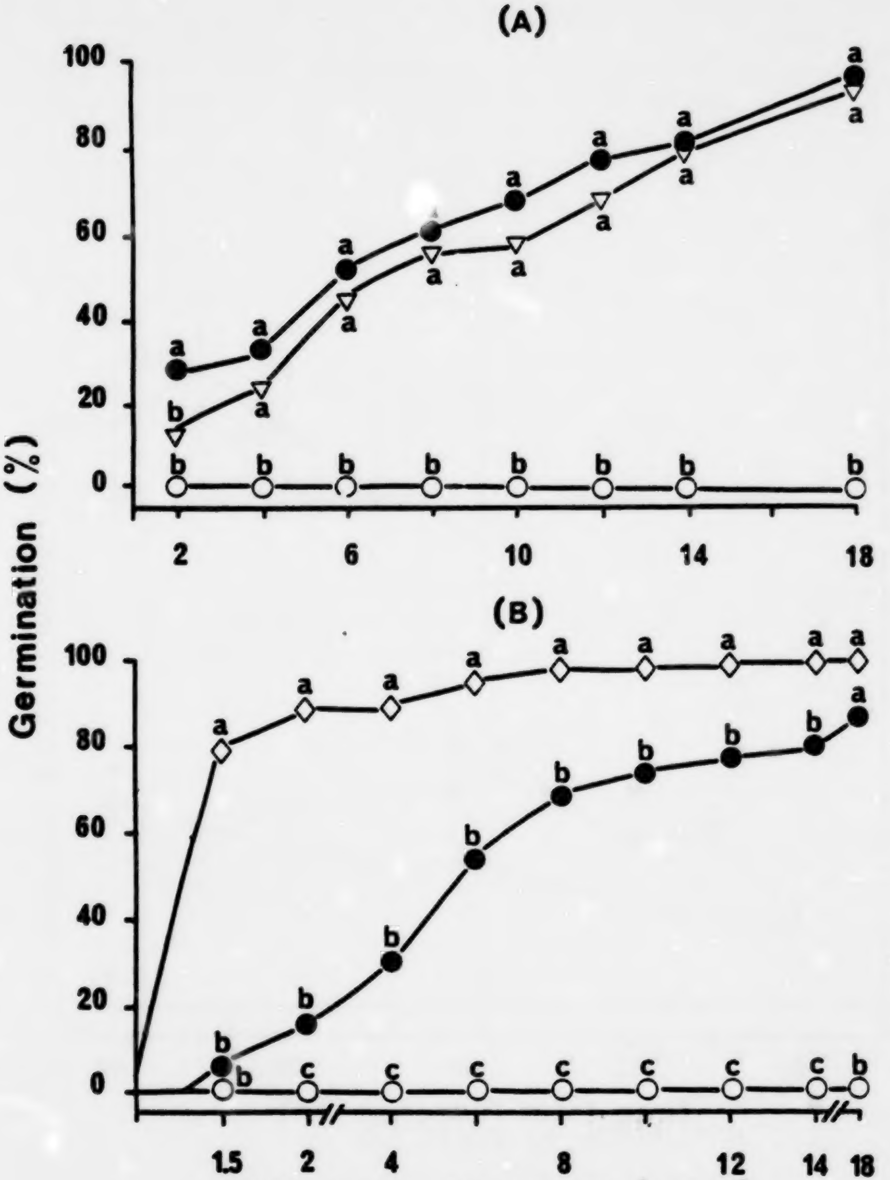

Fig. 3 (A) Effect on germination of piercing the dormant, imbibed caryopsis and leaving the hole uncovered (●) or sealing it immediately with lanolin (▽). The controls (○) were not pierced. The hole was pierced in the center of the abaxial (anti-raphe) surface of the caryopsis, 4 mm from the micropylar end. Means at the same time from treatment labelled with different letters are significantly different at the 5% level.
(B) As in (A), except that the hole was supplied with water by covering it with a strip of wet filter paper (◇).

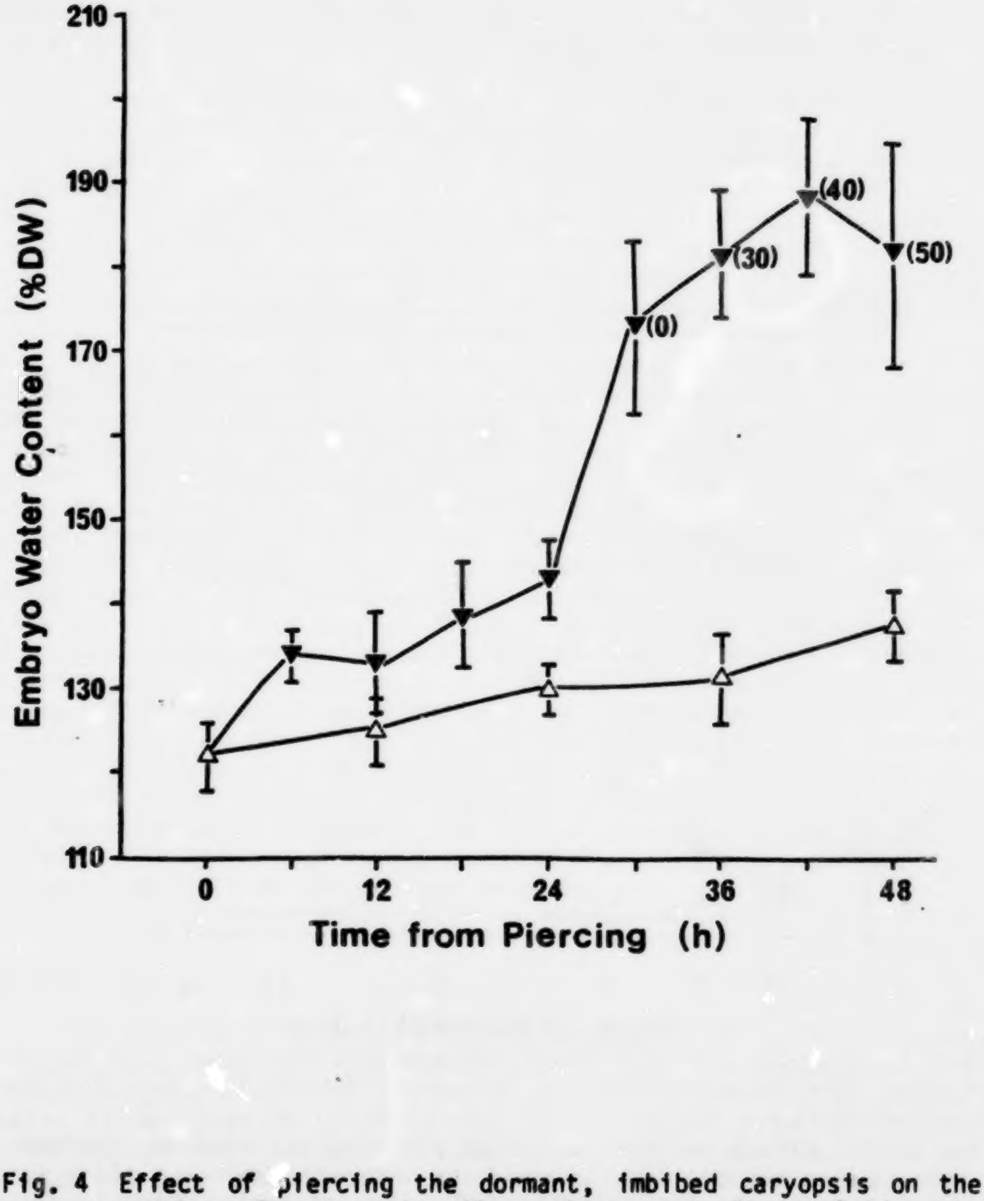

Fig. 4 Effect of piercing the dormant, imbibed caryopsis on the uptake of water by the embryo and its relation to germination. The piercing treatment was as described in Fig. 3, with the hole left uncovered. Percent germination of the pierced seeds (▼) is shown in brackets; there was no germination of the unpierced controls (△). All data area means of 10 replicates per treatment. Standard errors of the means are shown by vertical lines.

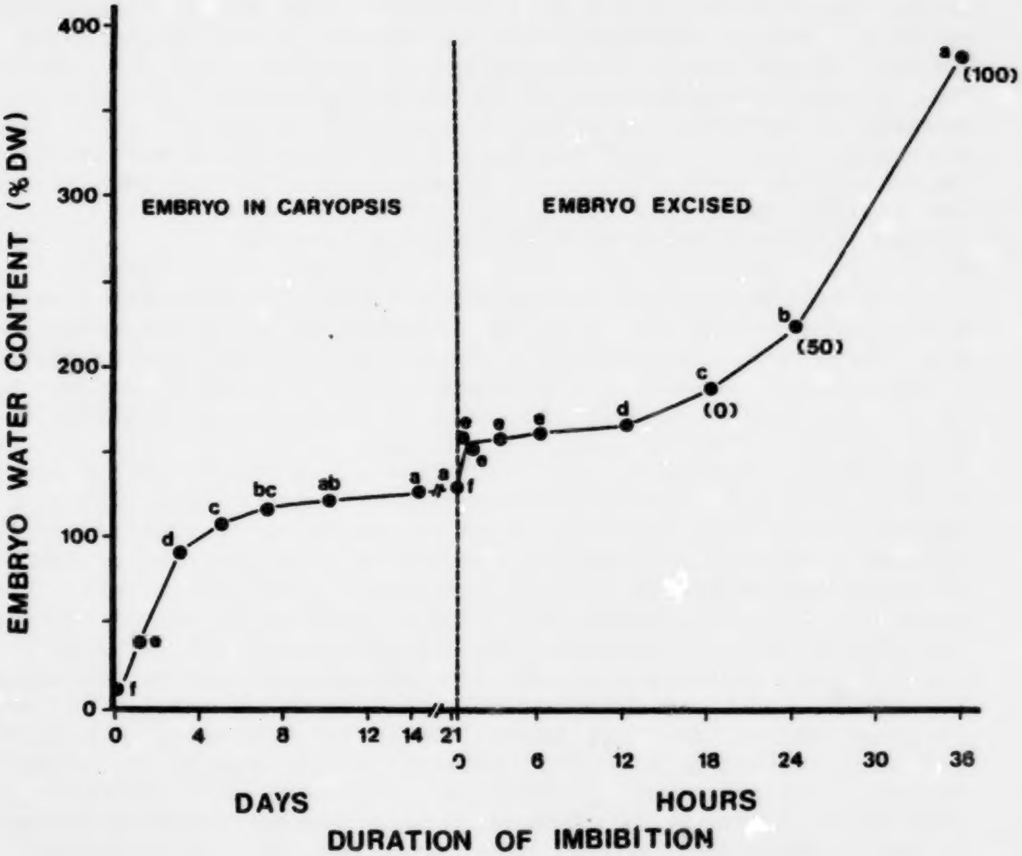

Fig. 5 Uptake of water by the embryo (a) while enclosed in the intact caryopsis and (b) after having been excised and placed on wet filter paper. Percent germination is shown in brackets. All data are means of 10 replicates per sample. Means labelled with different letters are significantly different at the 5% level.

might be suggested that germination of the isolated embryo could have been caused by the loss of a diffusible germination inhibitor. However, the fact that germination was induced by piercing or cutting the caryopsis, even when the hole or cut surface was immediately sealed with lanolin, is not consistent with this hypothesis. Hay (1962) conducted a similar experiment with wild oats with the same result, and he also concluded that the loss of a germination inhibitor could not be involved. The ineffectiveness of the lanolin application in preventing germination also provided evidence that the response could not be attributed to an increase in the oxygen supply. This conclusion received further support from a later experiment in which the caryopsis was cut below the surface of degassed (oxygen free) water. The cut surface was then kept below the surface of the water until germination was complete (approximately 36 hours). This treatment, which would prevent any increase in the oxygen supply, caused no delay in germination as compared with the controls which were cut in air.

It may be assumed, on the basis of the present hypothesis, that a major factor affecting the transport of the imbibed water of the embryo will be the hydraulic conductivity of the overlying tissues. There is evidence that changes in this factor may be one of the mechanisms by which the parent plant environment may influence the degree of dormancy of the seed. Several investigators have reported that when wild oat plants are subjected to water stress by increasing the temperature or reducing the supply of water to the roots, the dormancy of the seeds is significantly reduced (Peters, 1982; Sawhney and Naylor, 1982; Sexsmith, 1969). Although the mechanism involved was not investigated, Wellington and Durham (1961) reported that, in wheat, dry, warm weather during the period of seed maturation increased the rate of germination, and they provided evidence that this effect was due to increased hydraulic conductivity of the tissues enclosing the embryo. It was also reported by Khan and Laude (1969) that, in barley, a brief exposure of the plants to high temperature resulted in grains with thinner coats that took up water and germinated more quickly. In view of these results it would seem worthwhile to determine whether the well-established effects of water stress on seed dormancy in wild oats can be similarly explained.

The supply of water to the embryo will be determined not only by the conductivity of the overlying tissues but also by factors affecting the potential of the imbibed water. Thus to account for the effect of mechanical injury on germination (Hsaio et al., in press) it was suggested, as a working hypothesis, that the localized destruction of the tissues may cause an increase in the potential of the imbibed water at the site of injury, and that the water potential gradient then established will promote the uptake of water by the embryo, increasing its water content to the critical level required to trigger the onset of germination. This hypothesis was in good agreement with the subsequent experiments which are summarized in the present report (Figs. 4 and 5).

More direct evidence of a correlation between the germination of wild oats and the potential of the imbibed water was provided by Hsiao and Simpson (1971) in a study of the effect of various wavelengths of light on germination. It was shown that the light-induced inhibition of germination could be eliminated merely by increasing the volume of water in which the seeds were imbibed. Measurements with a thermocouple psychrometer showed that the additional water increased the water potential of the imbibed caryopsis and that, at both water levels, seeds kept in the dark had higher water potentials than those in the light. Another interesting feature of these data was that, under comparable conditions of light exposure and water supply, nondormant seeds had considerably higher water potentials than those which were dormant. This observation agrees well with the present hypothesis and suggests the need for a more comprehensive investigation designed to determine whether the marked differences in the degree of dormancy which have been shown to exist between genetically distinct strains of wild oats (Naylor and Jana, 1976) are correlated with differences in the water potential of the imbibed caryopsis.

A further test of the validity of the proposed hypothesis is its ability to account for the loss of dormancy in wild oats which occurs during dry storage, i.e. the process of "afterripening." There would seem to be at least two possible mechanisms by which this process could be caused by factors affecting the uptake and distribution of water. One possibility is that increased desiccation during storage may cause structural changes which will increase the hydraulic conductivity of tissues enclosing the embryo. Although there is no reported evidence of this effect, the fact that the rate of afterripening is increased by warm, dry conditions (Banting, 1966) is consistent with this hypothesis.

An alternative explanation is that there may be an accumulation of solutes in the embryo which would promote the uptake of water by reducing the osmotic potential. There is, however, no direct evidence in the literature of such an effect. Although Naylor and Simpson (1961) showed that sucrose increased germination when supplied exogenously to partially afterripened embryos of wild oats, they found no increase in the level of endogenous sucrose after storage for two years. They did not rule out the possibility, however, that accumulation of other sugars may occur. They also showed that gibberellic acid (GA_3) interacted synergistically with exogenous sucrose in promoting germination. Since GA_3 has been reported to increase the hydrolysis of sucrose in stem segments of Avena (Kaufman et al., 1973) and in other species (Katsumi and Kazama, 1978), its effect on germination is consistent with the hypothesis that the level of glucose, which is a major source of carbohydrate nutrition for the wild oat embryo (Chen and Varner,

1969) may be a factor of greater significance. Certainly, it would seem worthwhile to examine the relationship between afterripening and the accumulation of specific sugars, and the possible correlation with changes in osmotic potential.

While water uptake by the embryo will be dependent on the water potential gradient between the embryo and the enclosing tissues, it seems likely that, in the field, the soil water potential and the resistance to water flux at the seed-soil interface (discussed by Koller and Handas, 1982) will more frequently be the limiting factors. Clearly, it is the latter components which will determine the maximum potential that can be achieved by the tissues of the caryopsis, and that can thus determine whether the supply of water to the embryo will reach the critical level required for the induction of germination.

In discussing the many factors that may play a role in the mechanism of seed dormancy in wild oats, Simpson (1978) emphasized that many of the metabolic systems of the dormant seed remain active, and that it is only part of the total system which is arrested (or functioning at a suboptimal level?) when the seed is in a dormant condition. He concluded that "from the available evidence it seems logical to assume that it is the environment around the seed that initiates both the disengagement and reentrainment of the subsystems that are temporarily nonfunctional." Of the few environmental requirements for seed germination, water is undoubtedly the one with the greatest capacity for germination control. The results of the present investigation suggest that this factor may play a major role in the regulation of seed dormancy in wild oats. Much further work remains to be done, however, to test the validity of this hypothesis.

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REFERENCES

Atwood, W. M. 1914. A physiological study of germination of Avena fatua. Bot. Gaz. 57:386-414.

Banting, J. D. 1966. Studies on the persistence of Avena fatua. Can. J. Plant Sci. 46:129-140.

Chen, S. S. C. and J. E. Varner. 1969. Metabolism of ^{14}C-maltose in Avena fatua seeds during germination. Plant Physiol. 44:770-777.

Crocker, W. 1906. Role of seed coats in germination. Bot. Gaz. 42: 265-291.

Hay, J. R. 1962. Experiments on the mechanism of induced dormancy in wild oats, *Avena fatua* L. Can. J. Bot. 40: 191-202.

Hsiao, A. I. 1979. Effect of sodium hypochlorite and gibberellic acid on seed dormancy and germination of wild oats (*Avena fatua*). Can. J. Bot. 57: 1729-1734.

Hsiao, A. I., and G. M. Simpson. 1971. Dormancy studies in seed of *Avena fatua.* 7. The effects of light and variation in water regime on germination. Can. J. Bot. 49: 1347-1357.

Hsiao, A. I., G. I. McIntyre, and J. A. Hanes. In press. Seed dormancy in *Avena fatua*. I. Induction of germination by mechanical injury. Bot. Gaz. 144.

Ikuma, H., and K. V. Thimann. 1963. The role of the seed coats in germination of photosensitive lettuce seeds. Plant & Cell Physiol. 4: 169-185.

Jana, S., N. Acharya, and J. M. Naylor. 1979. Dormancy studies in seed of *Avena fatua*. 10. On the inheritance of germination behaviour. Can. J. Bot. 57: 1663-1667.

Katsumi, M., and H. Kazama. 1978. Gibberellin control of cell elongation in cucumber hypocotyl sections. Bot. Mag. Tokyo Special Issue 1: 141-158.

Kaufman, P. B., N. S. Ghosh, J. D. Lacroix, S. L. Soni, and H. Ikuma. 1973. Regulation of invertase levels in *Avena* stem segments by gibberellic acid, sucrose, glucose and fructose. Plant Physiol. 52: 221-228.

Khan, R. A., and H. M. Laude. 1969. Influence of heat stress during seed maturation on germinability of barley seed at harvest. Crop Sci. 9: 55-58.

Koller, D., and A. Handas. 1982. Water relations in the germination of seeds, p. 401-431. *In* O. L. Lange, D. S. Nobel, C. B. Osmond, and H. Ziegler (ed.) Physiology plant ecology. II. Water relations and carbon assimilation. Encycl. Plant Physiol. N.S. Vol. 12B, Springer-Verlag, Berlin.

Naylor, J. M., and S. Jana. 1976. Genetic adaptation for seed dormancy in *Avena fatua*. Can. J. Bot. 54: 306-312.

Naylor, J. M., and G. M. Simpson. 1961. Dormancy studies in seed of *Avena fatua*. 2. A gibberellin-sensitive inhibitory mechanism in the embryo. Can. J. Bot. 39: 281-295.

Peters, N. C. B. 1982. The dormancy of wild oat seed (Avena fatua L.) from plants grown under various temperature and soil moisture conditions. Weed Res. 22: 205-212.

Sawhney, R., and J. M. Naylor. 1982. Dormancy studies in seed of Avena fatua. 13. Influence of drought stress during seed development on duration of seed dormancy. Can. J. Bot. 60: 1016-1020.

Sexsmith, J. J. 1969. Dormancy of wild oat seed produced under various temperature and moisture conditions. Weed Sci. 17: 405-407.

Simpson, G. M. 1978. Metabolic regulation of dormancy in seeds -- a case history of the wild (Avena fatua), p. 167-220. In M. E. Clutter (ed.) Dormancy and development arrest. Experimental analysis in plants and animals. Academic Press, New York.

Wellington, P. S., and V. M. Durham. 1961. Studies on the germination of cereals. 3. The effect of the covering layers on the uptake of water by the embryo of the wheat grain. Ann. Bot. N.S. 25: 185-196.

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Use and Mode of Action of Wild Oat Herbicides

Editors: Allan E. Smith and Andrew I. Hsiao

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FOREWORD

This second volume of proceedings from the Wild Oat Symposium held at Regina on October 18 and 19, 1983, has been produced to include further manuscripts and to describe the progress being made in the area of mode of action research. This latter aspect was covered during the evening of October 18, 1983 when scientists from the companies manufacturing wild oat herbicides discussed the mechanisms whereby herbicides control wild oats.

Special thanks are due to Dr. M. Evelyn Jonescu, Director, Canadian Plains Research Center, University of Regina, for kindly agreeing to publish this second volume as a companion volume to that already published by the Center. Our thanks are also expressed to Gillian Wadsworth Minifie, Coordinator of Publications for the Canadian Plains Research Center, for her excellent editorial work.

A. E. Smith and A. I. Hsiao
Editorial Committee

APPENDIX

Common and chemical names of herbicides mentioned in the text (according to the Canadian Standards Association)

Asulam	methyl 4-aminobenzenesulphonylcarbamate
Atrazine	2-chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine
Barban	4-chlorobut-2-ynyl 3-chlorophenylcarbamate
Benzoylprop-ethyl	ethyl(±)2-(*N*-benzoyl-3,4-dichloroanilino)-propionate
Bromoxynil	3,5-dibromo-4-hydroxybenzonitrile
CDAA	*N*,*N*-diallyl-2-chloroacetamide
CDEC	2-chloroallyl diethyldithiocarbamate
Chlorpropham	isopropyl 3-chlorophenylcarbamate
Chlorsulfuron	2-chloro-N-[(4-methoxy-6-methyl-1,3,5-triazin-2-yl) aminocarbonyl]benzenesulfonamide
Dalapon	2,2-dichloropropionic acid
Diallate	*S*-(2,3-dichloroallyl) diisopropylthiocarbamate
Dicamba	3,6-dichloro-2-methoxybenzoic acid
Dichlorprop	(±)-2-(2,4-dichlorophenoxy)propionic acid
Diclofop-methyl	methyl (±)-2-[4-(2,4-dichlorophenoxy)phenoxy]-propionate
Difenzoquat	1,2-dimethyl-3,5-diphenylpyrazolium methyl sulphate
Dinitramine	*N'*,*N'*-diethyl-2,6-dinitro-4-trifluoromethyl-*m*-phenylenediamine
Dinoseb	2-*sec*-butyl-4,6-dinitrophenol
EPTC	*S*-ethyl dipropylthiocarbamate
Flamprop-methyl	methyl *N*-benzoyl-*N*-(3-chloro-4-fluorophenyl)-2-aminopropionate
Ioxynil	4-hydroxy-3,5-diiodobenzonitrile
Linuron	3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea
MCPA	4-chloro-2-methylphenoxyacetic acid

Mecoprop	(±)-2-(4-chloro-2-methylphenoxy)propionic acid
Metribuzin	4-amino-6-*tert*-butyl-4,5-dihydro-3-methylthio-1,2,4-triazin-5-one
MH	maleic hydrazide
MSMA	monosodium methanearsonate
Paraquat	1,1'-dimethyl-4,4'-dipyridilium di-ion
Picloram	4-amino-3,5,6-trichloropicolinic acid
Propanil	3',4'-dichloropropionanilide
Propham	isopropyl phenylcarbamate
Sethoxydim	2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexene-1-one
TCA	trichloroacetic acid
2,4-D	2,4-dichlorophenoxyacetic acid
2,4-DB	4-(2,4-dichlorophenoxy)butyric acid
2,4,5-T	2,4,5-trichlorophenoxyacetic acid
Triallate	*S*-2,3,3-trichloroallyl diisopropylthiocarbamate
Trifluralin	2,6-dinitro-*N*,*N*-dipropyl-4-trifluoromethylaniline

WILD OAT SYMPOSIUM:
PROCEEDINGS, Volume 2

Use and Mode of Action
of Wild Oat Herbicides

A REVIEW OF DORMANCY IN WILD OATS AND THE LESSON IT CONTAINS FOR TODAY

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ABSTRACT

Dormancy in Avena fatua is a complex phenomenon involving genotype/environment interactions that produce a range of expressions within a population at any one period of time. Mechanisms producing variation include environmental and hormonal control of biochemical pathways which can interact with components of seed structure to produce differing levels of primary and secondary dormancy across a range of genotypes. There is currently no single solution to overcoming seed dormancy in this species.

The first important paper on wild oat seed dormancy was published by Atwood (1914). It is interesting that he worked with seed obtained from Indian Head and that, in the main, his conclusions remain accepted. He noted that (a) some wild oat seeds are dormant; (b) dormancy is lost with time under the influence of external environmental factors and internal changes; (c) pricking and removing hulls speeds up loss of dormancy; (d) some dormancy can be overcome by increasing oxygen tension in the atmosphere; and (e) light does not affect dormancy. The last effect has since been shown not to be true (Hsiao and Simpson, 1971). Atwood's conclusions are summarized in Fig. 1.

Since Atwood's time, there has been the general idea that if dormancy could be eliminated by some means, for example, by spraying a chemical on the plant or into the soil to catch buried seed, this might end the wild oat problem. This is certainly a common view among farmers.

In Canada in the late forties and middle fifties, scientists like Banting (1962), Friesen (1961) and Hay (1962) made important contributions to the understanding of how long wild oats can persist and which environmental factors induce and maintain seed dormancy.

By the late fifties, we understood that dormancy is a complicated phenomenon, not simply an on/off state in seeds. For example, we had come to realise that (a) not all wild oat seeds are dormant; (b) primary dormancy may occur in newly-shed seeds and secondary, or induced, dormancy can be established under

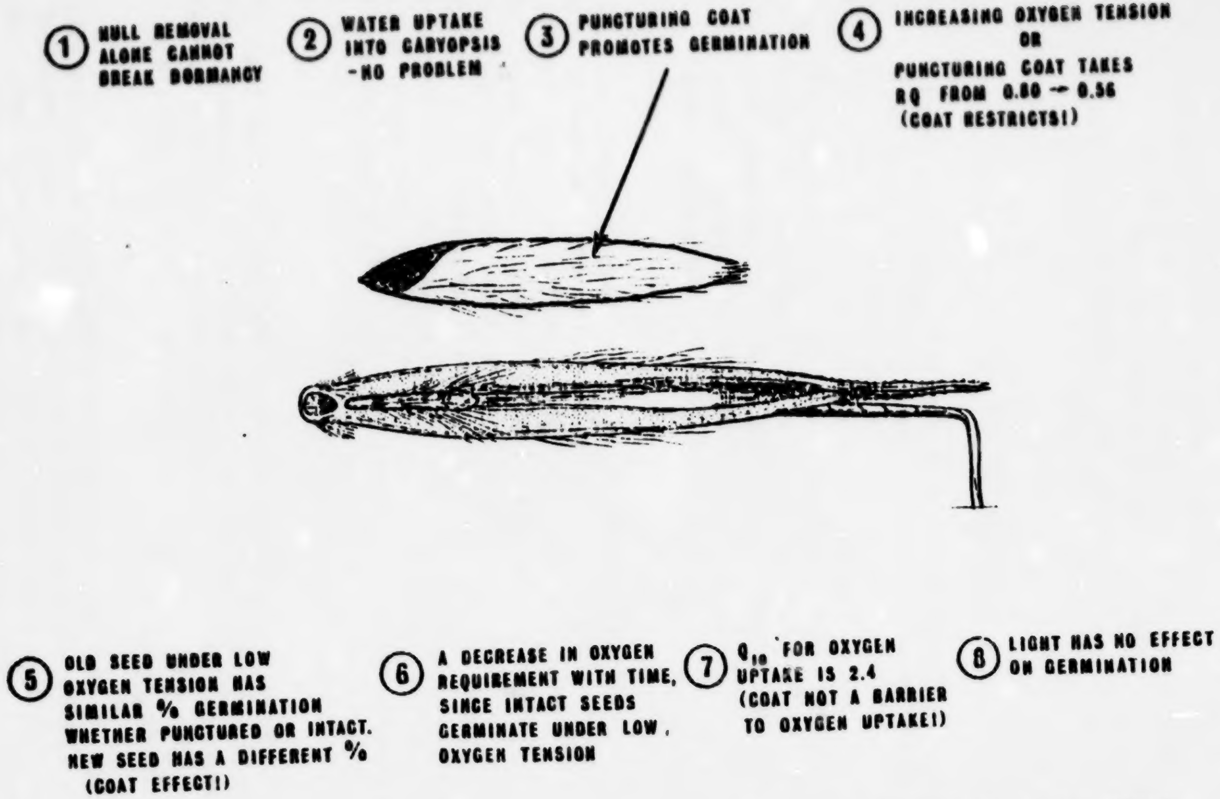

① HULL REMOVAL ALONE CANNOT BREAK DORMANCY
② WATER UPTAKE INTO CARYOPSIS -NO PROBLEM
③ PUNCTURING COAT PROMOTES GERMINATION
④ INCREASING OXYGEN TENSION OR PUNCTURING COAT TAKES RQ FROM 0.80 → 0.56 (COAT RESTRICTS!)
⑤ OLD SEED UNDER LOW OXYGEN TENSION HAS SIMILAR % GERMINATION WHETHER PUNCTURED OR INTACT. NEW SEED HAS A DIFFERENT % (COAT EFFECT!)
⑥ A DECREASE IN OXYGEN REQUIREMENT WITH TIME, SINCE INTACT SEEDS GERMINATE UNDER LOW, OXYGEN TENSION
⑦ Q10 FOR OXYGEN UPTAKE IS 2.4 (COAT NOT A BARRIER TO OXYGEN UPTAKE!)
⑧ LIGHT HAS NO EFFECT ON GERMINATION

Fig. 1 Atwood's conclusions (1914) on the nature of seed dormancy in Avena fatua.

certain conditions; (c) dormancy can be broken naturally by "after-ripening." That is, certain environmental factors can overcome dormancy after a period of time has elapsed. Several artificial ways of breaking dormancy were also found, such as treatment with gibberellic acid (Green and Helgeson, 1957), nitrate (Major and Roberts, 1968), oxygen (Baker and Leighty, 1958), and specific respiratory poisons, such as cyanide (Major and Roberts, 1968) and azide (Fay and Gorecki, 1978).

Since I entered the field twenty-five years ago, by coming to work with Professor J. Naylor, Agriculture Canada has supported our research in what must be one of the more comprehensive studies of seed dormancy made anywhere. This is a good example of the way in which basic long-term research can provide the background to understanding a serious agricultural problem. Although today there are approximately thirty herbicides that can control wild oats to some degree, the species still persists as a world-wide agricultural problem, due primarily to the occurrence of seed dormancy which sustains large populations of buried seeds. Finding an economic method to prevent or overcome seed dormancy is still of prime interest if complete control over wild oats is to be gained. Thus, our research is a search for the physiological and genetic bases of seed dormancy so that a way of exploiting weak points in the cycle of induction, maintenance and removal of dormancy that occur naturally in prairie wild oat populations can be discovered.

Since 1960, and especially over the last ten years of the Wild Oat Action Committee, about thirty scientific papers have come from the Naylor group. At the same time, a similar number of publications on seed dormancy in Avena fatua have appeared around the world, primarily in the United Kingdom and Australia. All of this work has helped to paint a picture of the complicated nature of the expression of seed dormancy in the wild oat.

Five years ago I published a review (Simpson, 1978) of progress to that date in the world-wide research effort to understand seed dormancy in wild oats. At that point, half-way through the life of the Wild Oat Action Committee, the general picture could be summarized as follows:

a. Research of the sixties had shown that dormancy was very complicated. It was not an on/off state but rather a complicated relationship between each seed and its particular environment, not just for germination, but for all the preceding environmental experience of the seed on the parent plant, as well as after abscission from the parent plant. We had come to understand that a number of different states of dormancy can exist according to both the genetic origins and the past experience of each seed.

b. We were able to say with some confidence that (i) different genetic strains express a range of germination responses to the same conditions. Some are highly dormant whereas others show essentially no dormancy; (ii) even on the same plant there can be differences in the degree of dormancy due to the fact that the environment around the maturing plant can influence the induction of dormancy. Primary and secondary seeds in the same spikelet can exhibit different levels of dormancy; (iii) there are distinctions between primary dormancy induced on the parent plant and secondary dormancy induced in the seed after it is shed from the parent plant; (iv) dormancy can persist for different lengths of time and this is related to the particular environments experienced both on the parent plant and during after-ripening following abscission; (v) each different expression of seed dormancy requires a different environmental cue to overcome the dormancy.

It is not necessary to understand the physiological basis of the different forms of dormancy to realize that at the population level it is of great advantage (adaptive significance) to the wild oat species to possess a range of expressions of dormancy. It simply means that some small portion of the wild oat seed population will always be able to find a niche of the environment to persist in. That is, some seeds will be dormant and persist in wet or dry areas, hot or cold areas, on or below the soil surface and in poorly oxygenated darkness and so on. This adaptive significance provides plasticity which is the basis for survival over a wide range of environments in a geographical sense. It is this plasticity at the population level that has made wild oats such a formidable weed in a range of environments around the world.

It was also found that within the seed the hulls, seed coat, embryo and endosperm each have significant roles in the expression of dormancy. For example, Upadhyaya et al. (1982a) showed that if the embryo is dormant, it must of necessity have endosperm that also has characteristics of dormancy, otherwise the endosperm would degrade spontaneously long before the embryo dormancy was lost. Because the embryo and endosperm are genetically different tissues, there must be a way in which these separate expressions of dormancy are integrated.

The rapidity with which our knowledge has increased in the last five years is due to our realisation of the importance of working with genetically diverse strains that are homogeneous within each strain. Wild oats are self-pollinated and, thus, it is possible to differentiate clearly between each strain. It is worthwhile pointing out that it was a team approach by a population geneticist, a cell biologist, a biochemist and a plant physiologist that produced the important changes in our research approaches and thinking.

In the middle seventies, we began comparing dormant and non-dormant populations for their response to gibberellic acid, which can break dormancy. We used this compound as a tool to determine the nature of the blocks to germination. From this work we developed a simplistic model (Fig. 2) for the action of a single gibberellin-like compound which is known to occur naturally in

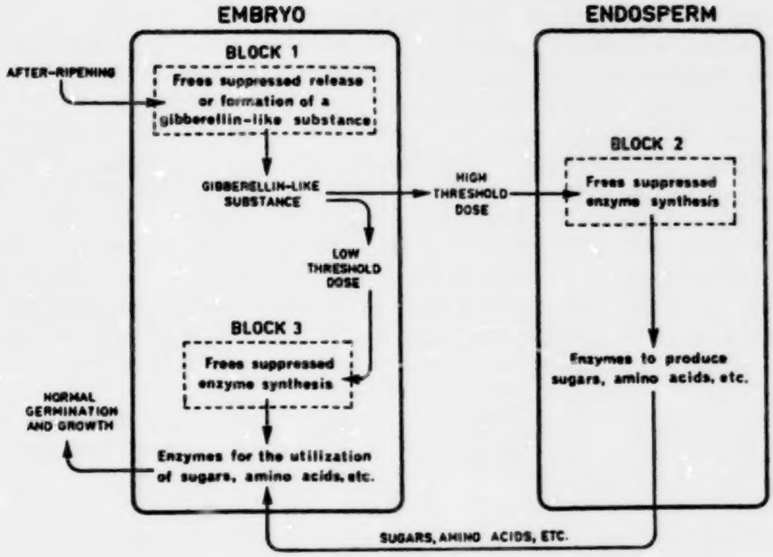

EMBRYO
ENDOSPERM
BLOCK 1
AFTER-RIPENING
Frees suppressed release or formation of a gibberellin-like substance
GIBBERELLIN-LIKE SUBSTANCE
HIGH THRESHOLD DOSE
BLOCK 2
Frees suppressed enzyme synthesis
LOW THRESHOLD DOSE
BLOCK 3
Frees suppressed enzyme synthesis
NORMAL GERMINATION AND GROWTH
Enzymes for the utilization of sugars, amino acids, etc.
Enzymes to produce sugars, amino acids, etc.
SUGARS, AMINO ACIDS, ETC.

Fig. 2 Pathways leading from release of dormancy by the effects of after-ripening to normal germination of Avena fatua seeds (Simpson, 1978).

wild oat seeds. Growth regulator levels were believed to be controlled by changes in the environment which occur during the natural processes of after-ripening. Dr. Hsiao developed this model further by demonstrating that light and water can operate alone or together to influence the same system (Hsiao and Simpson, 1971).

About this time, we began to realise that the embryo can behave quite differently from its surrounding maternal tissue, the endosperm and aleurone. For this reason, we sought an explanation of the effects of gibberellin within the respiratory metabolic system of the embryo. We had known for some time that both dormant and non-dormant embryos respired in a superficially similar manner when put in conditions that support the normal germination of the non-dormant seeds. A Ph.D. study (Simmonds and Simpson, 1972) set us off on a search to prove whether or not the pentose phosphate pathway of respiration was the site of a block that caused embryo dormancy. Simmonds developed the first model of a biochemical nature that might account for the way oxygen could overcome dormancy (Simmonds and Simpson, 1972) (Fig. 3).

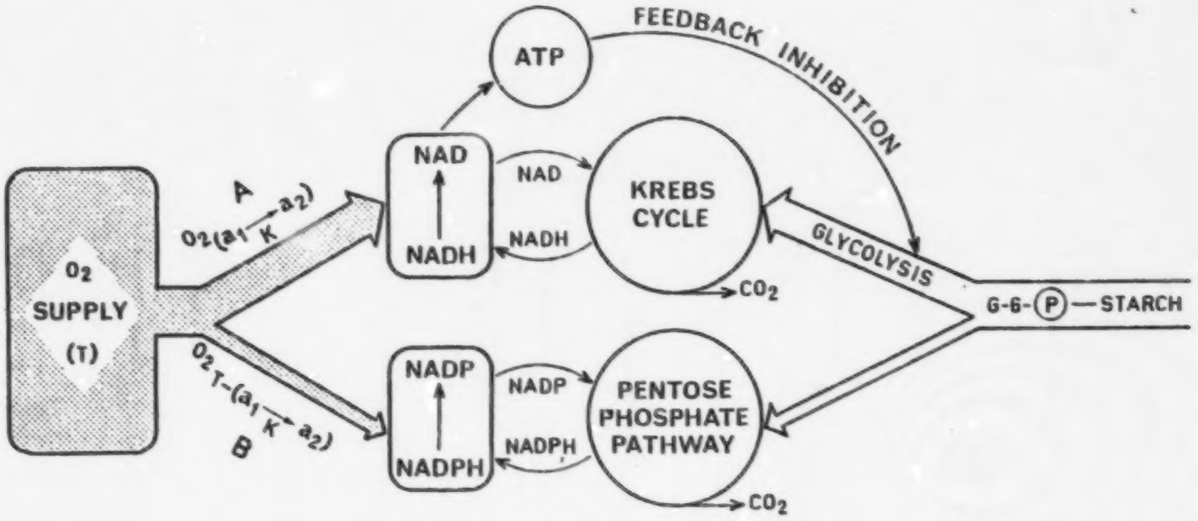
Unfortunately, this research finished in a dead end when Fuerst et al. (1983) demonstrated that the pentose phosphate pathway has a role in germination, but not in the initial release of dormancy (Fig. 4). When dormancy was overcome by gibberellin, there was no change in the activity of the pathway.

The possibility was then considered that the other end of the respiratory pathway, where electrons are transferred to oxygen, was a site of control for expressing dormancy. Activity of the electron transfer chain permits the production of NADPH and NADH which are important in the synthetic reactions associated with germination (Fig. 5). By using certain selective respiratory poisons that block the several pathways leading to acceptance of electrons by cytochromes (Upadhyaya *et al.*, 1982b, 1983; and Adkins *et al.*, In Press) have demonstrated that dormancy can be overcome by altering the activity of specific respiratory pathways. Azide and nitrate act in different ways to break dormancy (Table 1). The action of azide can be interpreted (Upadhyaya *et al.*, 1983) in part as a dependency on the activity of the alternative pathway of respiration since SHAM (salicylhydroxamic acid), which is an inhibitor of alternative respiration, prevents the dormancy-breaking effect of azide. The loss of dormancy from azide treatment may be due to a significant stimulation of NADH (Fig. 6) production necessary for the synthetic reactions of germination.

Table 1 Contrasting effects of azide and nitrate on oxygen uptake and the influence of salicylhydroxamic acid (SHAM), an inhibitor of the alternate pathway, on germination of dormant seeds of *Avena fatua*.

Treatment	Dormant seed (% Germination)	O_2 Uptake (nl min^{-1} $caryopsis^{-1}$)
H_2O	0	12
Azide	100	36
SHAM	0	12
NO_3^-	100	15
NO_2^-	100	15
NH_4^+	0	15
NO_3^- + SHAM	90	15
NO_2^- + SHAM	90	15

Nitrate, for example, in the form of common fertiliser, has long been known to break dormancy under field conditions. Adkins *et al.* (In Press) have demonstrated that nitrate breaks dormancy by affecting respiration in a different way from azide. Nitrate breaks dormancy by stimulating respiration, oxygen uptake, and by a mechanism that requires one or other of the two electron transfer systems (cytochrome chain and alternate pathway) to operate. When both these pathways are blocked, nitrate cannot stimulate germination. The need for one of the pathways to operate may be


FEEDBACK INHIBITION
ATP
O2 SUPPLY (T)
A
O2(a1 →K a2)
O2 T-(a1 →K a2)
B
NAD
NADH
NAD
NADH
KREBS CYCLE
CO2
GLYCOLYSIS
G-6-(P)—STARCH
NADP
NADPH
NADP
NADPH
PENTOSE PHOSPHATE PATHWAY
CO2

K_{min} when $T \underline{\Omega} a_1$			K_{max} when $T > a_1$		
	A	B		A	B
a_1	+ + + +	-	a_1	+ + + +	+
	+ + +	+		+ +	+ +
	+ +	+ +		+	+ + +
	+	+ + +	a_2	-	+ + + +
a_2	-	+ + + +			

a_1	Maximum oxygen consumption
a_2	Restricted oxygen consumption
K	Function of oxygen supply

Fig. 3 The regulation of oxidative metabolism of glucose by oxygen in the seed of Avena fatua. Relative activities within pathways vary from high (++++) to low (+) or zero (-). (From Simmonds and Simpson, 1972).

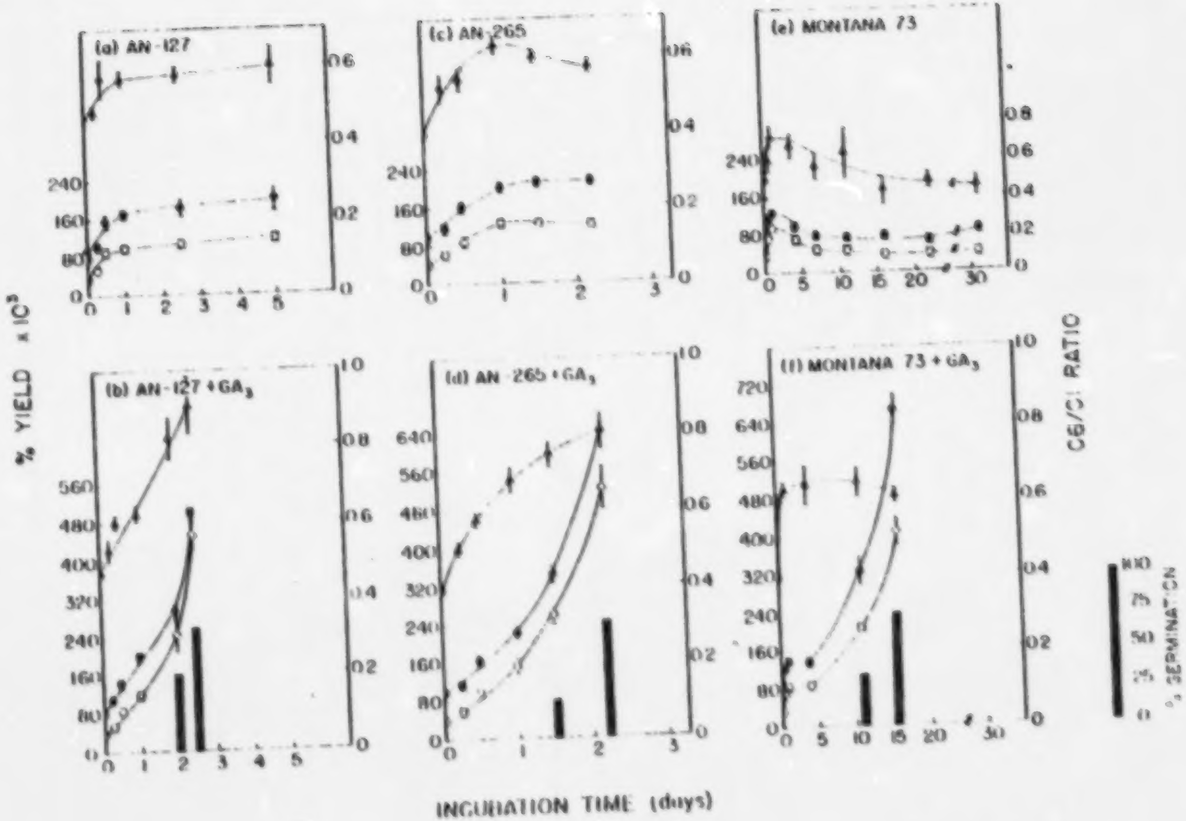


Fig. 4 Activity of the pentose phosphate pathway relative to glycolysis-Krebs cycle in dormant lines of *Avena fatua*. Lines AN-127, AN-265 and Montana 73. Controls a, c and e; GA_3 b, d and f. $^{14}CO_2$ yield from (6-^{14}C) glucose (●) and (1-^{14}C) glucose (○) and C6/C1 ratio (▲). Histograms are percent germination. (From Fuerst *et al.*, 1983).

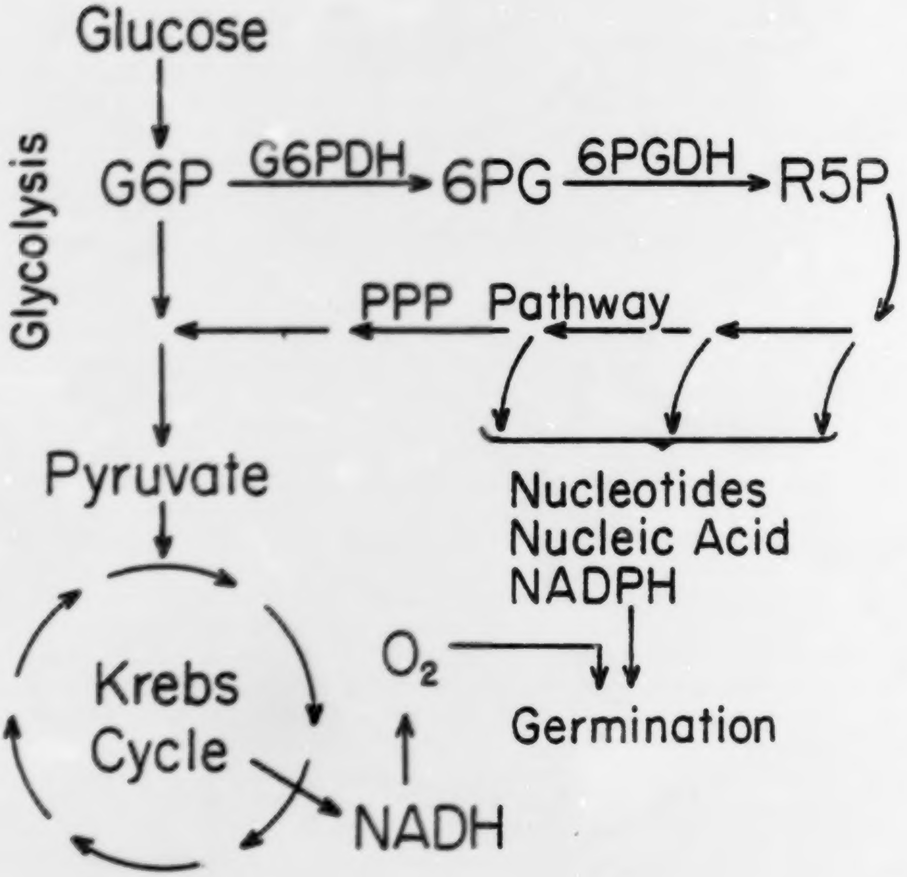

Glucose
Glycolysis
G6P
G6PDH
6PG
6PGDH
R5P
PPP Pathway
Pyruvate
Nucleotides
Nucleic Acid
NADPH
Krebs Cycle
O_2
Germination
NADH

Fig. 5 The key respiratory pathways for oxidation of glucose.

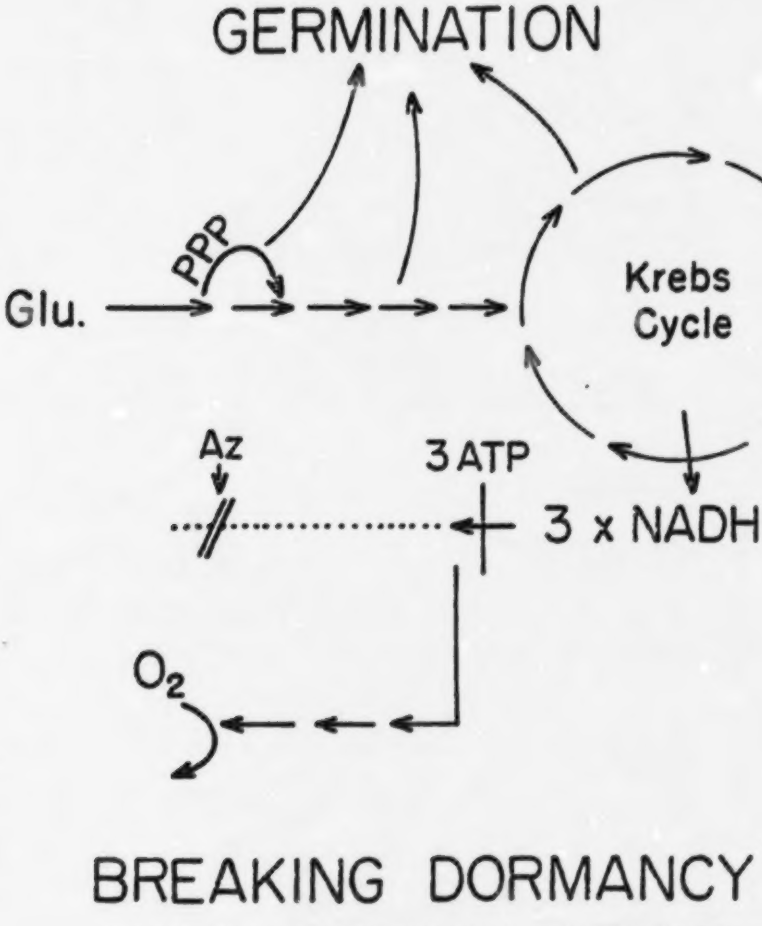

GERMINATION
PPP
Glu.
Krebs Cycle
Az
3 ATP
3 x NADH
O_2
BREAKING DORMANCY WITH SODIUM AZIDE

Fig. 6 The site of azide action in dormancy release of Avena fatua (after Upadhyaya et al., 1983).

related to the fact that ATP, the source of bond energy for making many compounds, has to be formed in large amounts. The nitrate effect may be related to a stimulation of the rate of turnover of the Krebs cycle to enhance the production of organic acids (Fig. 7) (Adkins *et al*., In Press).

Another interesting finding is Dr. Adkin's recent demonstration that ethanol can increase oxygen uptake and break dormancy by an effect that is different again from either azide, nitrate or gibberellin. His current interpretation is that ethanol may have two effects: one that is a direct effect on metabolism and the other as an anaesthetic-like effect on membranes. Thus, we can now see within the respiratory system of the embryo a number of points where dormancy can be broken by various artificial agents. This carries the implication that each one of the affected points in the system could be a natural point of blockage in the wild oat embryo. It is assumed that these natural points of blockage are overcome during after-ripening by internal and/or environmental changes (Fig. 8).

The picture of the embryo that emerges is that of a living sub-system that has normal biochemical activity in many of its parts, but these are rendered ineffective so far as germination is concerned because other parts of the system are inoperative.

Our understanding of the total system (Fig. 9) is mainly concentrated on the embryo, which is really only a small part of the whole dynamic system that consists not only of the seed, but also its surrounding environment which is always changing. Other research (Hsiao, 1979; Adkins and Ross, 1981) and a review of the extensive literature on wild oat research (Simpson, 1978) indicates that all these other parts of the seed/environment system have regulatory effects, directly or indirectly, on the actions of inducing, maintaining or removing dormancy in the wild oat seed. Furthermore, there is genetic diversity in every one of these subsystems of the seed. We are looking, therefore, at a complicated biological system which has great flexibility in expressing dormancy in a wide range of agronomic situations. This systems view is much more complicated than we had envisaged ten years ago.

Some of the implications from our current view of the complex nature of seed dormancy in *Avena fatua* are as follows:

1. We would certainly never have been able to reach this point of understanding without the continued long-term support of Agriculture Canada and NSERC. Our knowledge was built up slowly at first but, because it was basic knowledge, we have been able to build on the foundation more rapidly in the last several years. It is essential to keep up these basic studies, since without them it is impossible to interpret what is going on under agronomic conditions. We can now interpret with some confidence the behaviour of wild oat seeds under a range of agronomic conditions.

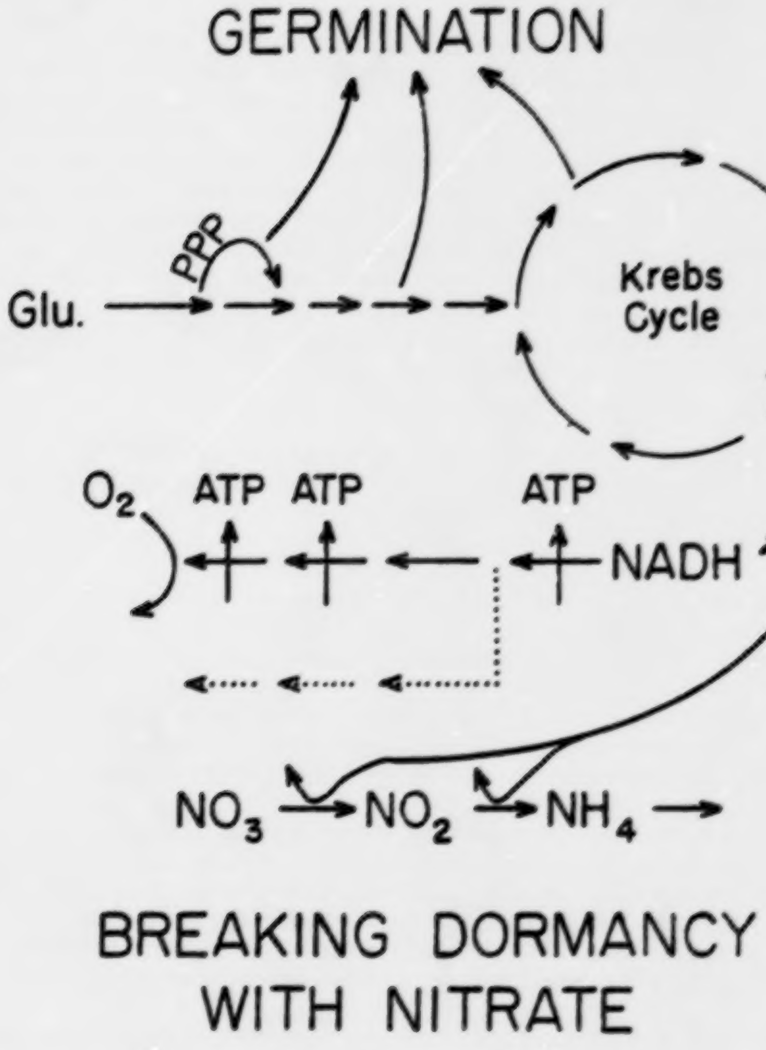
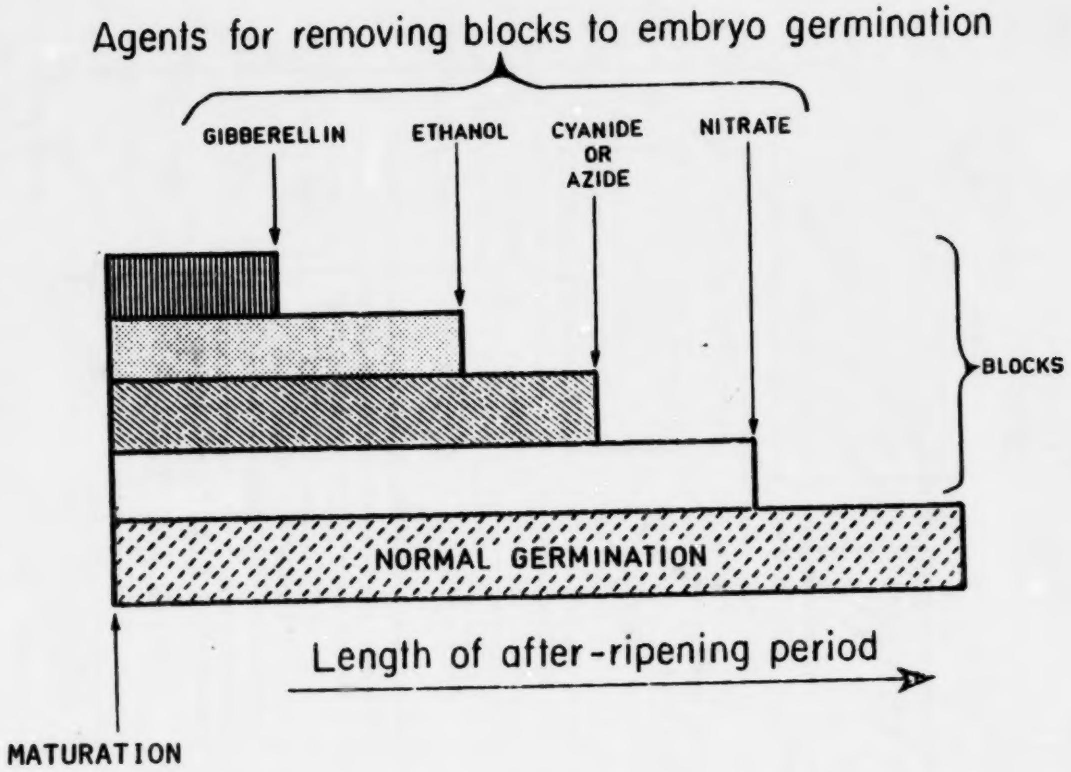

GERMINATION
PPP
Glu.
Krebs Cycle
O2
ATP
ATP
ATP
NADH
NO3
NO2
NH4
BREAKING DORMANCY WITH NITRATE

Fig. 7 A tentative role for the action of nitrate in breaking seed dormancy in _Avena_ _fatua_ (after Adkins _et_ _al_., In press).



Agents for removing blocks to embryo germination
GIBBERELLIN
ETHANOL
CYANIDE
OR
AZIDE
NITRATE
BLOCKS
NORMAL GERMINATION
Length of after-ripening period
MATURATION

Fig. 8 Several of the known physiological blocks to germination within the embryo of *Avena fatua*.

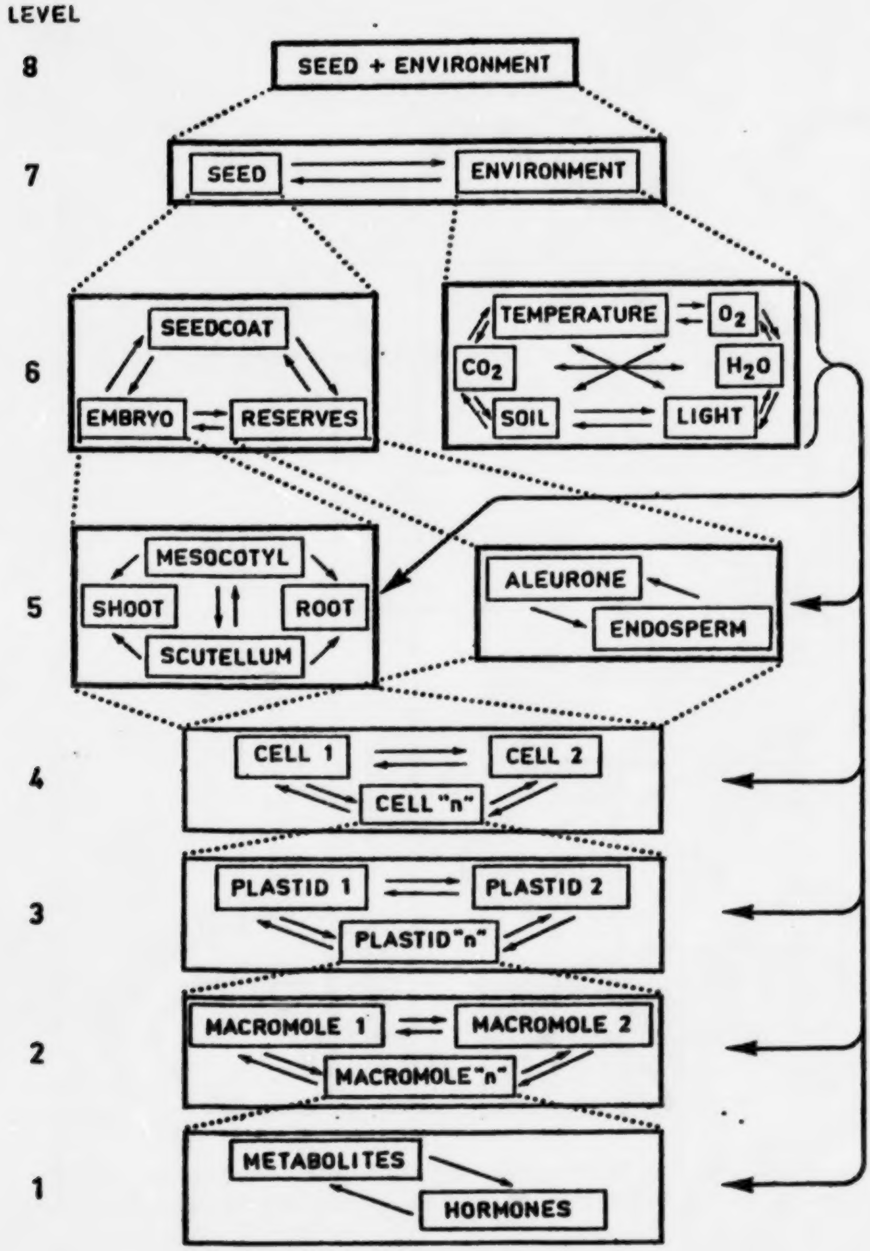

LEVEL
8
7
6
5
4
3
2
1
SEED + ENVIRONMENT
SEED
ENVIRONMENT
SEEDCOAT
EMBRYO
RESERVES
TEMPERATURE
O_2
CO_2
H_2O
SOIL
LIGHT
MESOCOTYL
SHOOT
ROOT
SCUTELLUM
ALEURONE
ENDOSPERM
CELL 1
CELL 2
CELL "n"
PLASTID 1
PLASTID 2
PLASTID "n"
MACROMOLE 1
MACROMOLE 2
MACROMOLE "n"
METABOLITES
HORMONES

Fig. 9 The position of the embryo in the hierarchy of levels of the seed-environment system for Avena fatua.

2. Our present view of the genetic variability and population plasticity of wild oats with respect to seed dormancy begs one obvious question. Has the use of specific agricultural practices, particularly the use of herbicides, promoted or decreased the incidence of seed dormancy? The answer is presently unclear but the work of Jana and Naylor (1982) suggests that shifts in genetic structure of wild oat populations can occur rapidly as a result of summerfallowing or herbicide use.

3. The prospect of eliminating seed dormancy by a single economic treatment, of whatever nature, does not look bright. There is no single substance, perhaps with the exception of gibberellins, that can be counted on to overcome all forms of dormancy. The use of gibberellins is not economically feasible.

4. A review of the literature of several hundred papers about wild oat seed dormancy indicates that much of the information published was of little value because the earlier workers, in particular, did not appreciate the genetic basis of seed dormancy. Collecting seeds from an elevator is not a sound basis for beginning a study of seed dormancy. It is also clear that progress has been much swifter and more successful where teams of people representing several disciplines have worked together. The cross-fertilization of understanding has led to the more widespread use of the same genetic stocks, better and more uniform environmental conditions for plant growth and seed storage, and an increase in uniformity of standards among the scientists interested in _Avena fatua_.

5. A significant point is that this kind of research is time-consuming even with the best scientists and financial support. The simple tedium of de-hulling this species must have consumed thousands of hours. The turnover time for each generation to produce a new batch of dormant seed under specified conditions is about four months.

6. There is a need to gather more information from around the prairie provinces about the degree of genetic variability within the general wild oat population. This is true not only for seed dormancy but also for other traits such as morphology. These obvious genetic traits must be related to such agronomic traits as herbicide and disease resistance and persistence under a range of agronomic conditions. If there is a move toward biological control of wild oats, this information will be of great value.

7. An important lesson is that, in relation to the real cost of wild oats in cereal agriculture in Canada, we have been too modest in supporting research on the heart of the wild oat problem, namely, seed dormancy. My guess is that in the twenty-five years that I have been involved in this area of

research, less than a total of $1 million has been spent in Canada, yet, in the same time, a conservative estimate of the real cost to Canada would be at least $2.5 billion!

8. Another lesson might be that there is probably a need for more long-term coordinated studies in weed biology for such a species as wild oats. There are still very large gaps in our knowledge, such as the nature of genetic variability, that limit and even prevent progress in other areas of investigation, such as herbicide resistance, disease resistance and so on, that all have a relationship with seed dormancy. The integrated weed control of the future will depend on the knowledge of all aspects of weed biology for each weed. This means more basic studies and not control measures alone.

9. Universities are not training enough of the specialists and generalists needed to make up the multi-disciplinary teams needed for solving the complex problems of biology. There is both a lack of trained Ph.D.s and lack of financial support for them in the research institutions.

10. Lastly, it is my opinion that the wild oat problem is not going to melt away. The world-wide effort in research has shown that a fair degree of control is possible. Nevertheless, because the wild oat is so adaptable, like microorganisms, it will probably keep one step ahead of our efforts. There is still a lot of research to be done.

REFERENCES

Adkins, S.W., and Ross, J.D. 1981. Studies in wild oat seed dormancy. I. The role of ethylene in dormancy breakage and germination of wild oat seeds (Avena fatua L.). Plant Physiol. 67: 358-362.

Adkins, S.W., Simpson, G.M., and Naylor, J.M. The physiological basis of seed dormancy in Avena fatua. III. Action of nitrogenous compounds. Physiol. Plant. (In press).

Adkins, S.W., Simpson, G.M., and Naylor, J.M. The physiological basis of seed dormancy in Avena fatua. IV. Alternative respiration and nitrogenous compounds. Physiol. Plant. (In press).

Atwood, W.M. 1914. A physiological study of the germination of Avena fatua. Bot. Gaz. 57: 386-414.

Baker, L.O., and Leighty, D.H. 1958. Germination studies with wild oat seeds. West. Weed Control Conf. Proc. 16: 69-74.

Banting, J.D. 1962. The dormancy behaviour of Avena fatua L. in cultivated soil. Can. J. Plant Sci. 42: 22-39.

Fay, P.K., and Gorecki, R.S. 1978. Stimulating germination of dormant wild oat (Avena fatua) seed with sodium azide. Weed Sci. 26: 323-326.

Friesen, H.A. 1961. Some factors affecting the control of wild oats with barban. Weeds 9: 185-194.

Fuerst, E.P., Upadhyaya, M.K., Simpson, G.M., Naylor, J.M., and Adkins, S.W. 1983. A study of the relationship between seed dormancy and pentose phosphate pathway activity in Avena fatua. Can. J. Bot. 61: 667-670.

Green, J.G., and Helgeson, E.A. 1957. The effect of gibberellic acid on dormant seed of wild oat. No. Cent. Weed Control Conf. Proc. 14: 39-40.

Hay, J.R. 1962. Experiments on the mechanism of induced dormancy in wild oats, Avena fatua L. Can. J. Bot. 40: 191-202.

Hsiao, A.I. 1979. The effect of sodium hypochlorite and gibberellic acid on seed dormancy and germination of wild oats (Avena fatua). Can. J. Bot. 57: 1729-1734.

Hsiao, A.I., and Simpson, G.M. 1971. Dormancy studies in seed of Avena fatua. 7. The effects of light and variation in water regime on germination. Can. J. Bot. 49: 1347-1357.

Jana, S., and Naylor, J.M. 1982. Adaptation for herbicide tolerance in populations of Avena fatua. Can. J. Bot. 60: 1611-1617.

Major, W., and Roberts, E.H. 1968. Dormancy in cereal seeds. I. The effects of oxygen and respiratory inhibitors. J. Exp. Bot. 19: 77-89.

Simmonds, J.A., and Simpson, G.M. 1972. Regulation of the Krebs cycle and pentosephosphate pathway activities in the control of dormancy of Avena fatua. Can. J. Bot. 50: 1041-1048.

Simpson, G.M. 1978. Metabolic regulation of dormancy in seeds - a case history of the wild oat (Avena fatua), p. 167-220. In M. Clutter (ed.) Dormancy and Developmental Arrest. Academic Press, New York.

Upadhyaya, M.K., Naylor, J.M., and Simpson, G.M. 1982a. Co-adaptation of seed dormancy and hormonal dependence of alpha-amylase production in endosperm segments of Avena fatua. Can. J. Bot. 60: 1142-1147.

Upadhyaya, M.K., Naylor, J.M., and Simpson, G.M. 1982b. The physiological basis of seed dormancy in Avena fatua L. 1. The action of the respiratory inhibitors sodium azide and salicylhydroxamic acid. Physiol. Plant. 54: 419-424.

Upadhyaya, M.K., Naylor, J.M., and Simpson, G.M. 1983. The physiological basis of seed dormancy in Avena fatua L. 2. On the involvement of alternative respiration in the stimulation of germination by sodium azide. Physiol. Plant. 58: 119-123.

USAGE OF WILD OAT HERBICIDES ACROSS THE PRAIRIES

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ABSTRACT

Wild oat herbicide usage has increased by 1,190% during the last decade. In 1982, a total of 9,605,959 ha was treated with wild oat herbicides, representing 64, 44, and 46% of cropped hectarage in Manitoba, Saskatchewan and Alberta respectively. Annual increases in hectarage treated with wild oat herbicides have slowed dramatically in recent years. Based on herbicide use statistics from Manitoba, it is estimated that wild oat herbicides cost Manitoba farmers $70,265,316 in 1982. Extrapolated to Alberta and Saskatchewan, it is estimated that the annual investment in wild oat herbicides by prairie farmers is $320,000,000. In coming years more precise information will be required in order that farmers can achieve maximum efficiency in controlling wild oats from this investment.

The number of herbicides available to farmers for wild oat control has greatly increased over the last decade. Farmers have rapidly accepted this chemical technology and put it into use. A review of wild oat herbicide use over the last decade can be used, in part, to gauge the Wild Oat Action Committee's success in fostering an awareness of the wild oat problem and of measures which can be taken to reduce losses due to this weed. However, these herbicide-use statistics should be viewed as more than just a historical listing of treated hectarage. Rather, they need to be interpreted with an eye to the future, for appropriate analysis of these figures can provide direction to future extension and research programming.

Data on wild oat herbicide-use in the prairie provinces have been published annually by the Economics Branch of Manitoba Agriculture since the late 1960s. The compilations are based on usage reported by the manufacturers of wild oat herbicides and, as such, are believed to represent an accurate reflection of actual use. These data (Fig. 1) illustrate the rapid increase in wild oat herbicide usage which has taken place over the last decade. Indeed, the area treated with wild oat herbicides has increased by more than 1,000% since the formation of the Wild Oat Action Committee, with a total of 9,605,959 hectares treated chemically for control of wild oats in 1982.

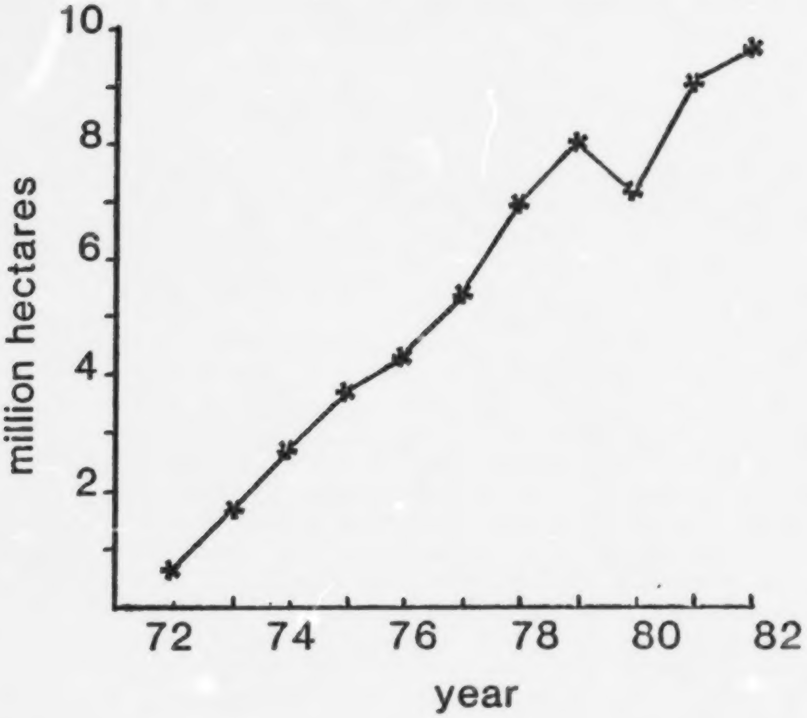

Fig. 1 Wild oat herbicide use in Western Canada.

This upward trend in the use of herbicides to control wild oats has continued virtually uninterrupted. The only year in which wild oat herbicide usage declined was 1980. This decline was associated with severe spring drought conditions in southern Manitoba and parts of southern Saskatchewan. As crop and weed emergence were erratic and yield potentials low, farmers were unwilling to invest in herbicides for controlling wild oats. By 1981, the upward trend in treated hectarage had resumed, and had already surpassed 1979 use-levels.

Although wild oat herbicide usage has expanded rapidly over the last decade, the rate of this expansion has slowed dramatically in recent years. From annual increases in treated hectarage of more than 70% in the early 1970s, the rate of increase has slowed to approximately 8% annually in the 1980s (Table 1). Slower expansion of the wild oat herbicide market has led to more aggressive competition among manufacturers of wild oat herbicides. Farmers, bombarded with conflicting advertising claims, are turning increasingly to extension personnel for assistance in developing wild oat control programmes for particular cropping situations. Future extension programmes must address this need for more specific information relating to the relative strengths and weaknesses of various herbicides for the control of wild oats.

Table 1 Annual increase in area treated with wild oat herbicides

Period	% Annual increase
1970 - 73	69.8
1971 - 74	72.8
1972 - 75	74.9
1973 - 76	39.3
1974 - 77	24.8
1975 - 78	23.1
1976 - 79	23.3
1977 - 80	11.7
1978 - 81	11.9
1979 - 82	8.6

When wild oat herbicide-use figures are examined on a provincial basis, a picture very similar to that for western Canada as a whole is seen. Herbicide use has increased rapidly over the last decade in all three provinces (Fig. 2). In Manitoba, however, the use of wild oat herbicides has reached a plateau and has failed to reach the peak of usage of 1979 since that time.

Although the total hectarage treated with wild oat herbicides is lower in Manitoba than the other provinces, the proportion of cropped hectares treated for wild oats is significantly higher (Table 2). This may relate to the greater production of less competitive special crops in Manitoba.

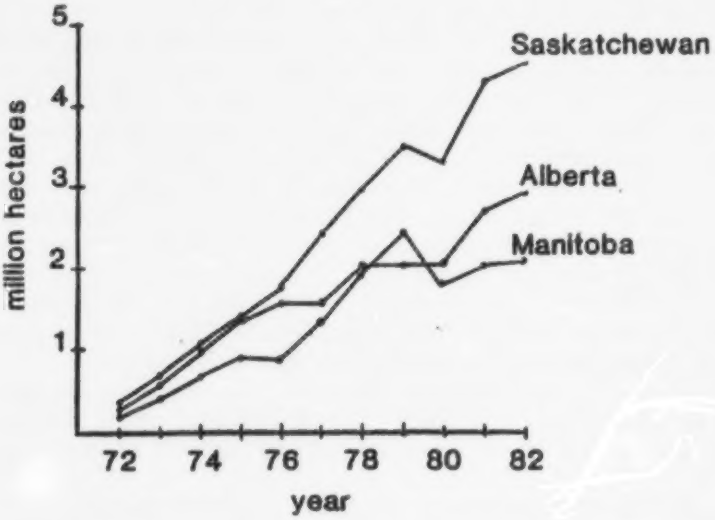

Fig. 2 Wild oat herbicide use by province.

Table 2 Wild oat herbicide use by province (1982)

Province	Hectares treated	% of cropped hectares
Alberta	2,941,683	46
Saskatchewan	4,531,385	44
Manitoba	2,103,752	64

A detailed examination of wild oat herbicide-use patterns in Manitoba is now possible as a result of changes incorporated into the Manitoba Crop Insurance questionnaire. This questionnaire now includes questions relating to:

a. weed problems
b. herbicide use
c. herbicide performance
d. crop tolerance to herbicides

This data base is comprehensive due to the high participation rate in the crop insurance programme. Data relating to herbicide use are analyzed by the Weeds Section on a crop district basis. Smaller geographical units could be analyzed where warranted. Data are currently available for the 1981 and 1982 use seasons. The data for 1983 will be obtained in the spring of 1984.

The data obtained from the crop insurance questionnaire allow us to develop a detailed picture of herbicide use in Manitoba. For example, the use of preemergence versus postemergence wild oat herbicides can be examined throughout the province (Fig. 3). Striking differences are apparent from district to district with respect to the use of preemergence wild oat herbicides in wheat. The use of preemergent wild oat herbicides is particularly favoured in the southwestern regions of the province. Ironically, this is the region of the province where soil moisture tends to be most limiting for crop production. As such, one might have expected herbicides which require incorporation to have been used less in this region than in other areas of the province. Greater use of preemergence wild oat herbicides in the southwest region of the province may be related to:

a. larger farm sizes which make it difficult to accomplish timely postemergence herbicide application
b. warmer soil conditions in the spring and lower soil organic matter contents which favour more consistent performance of soil applied herbicides in this region.

In examining preemergence versus postemergence wild oat herbicide use, it is interesting that preemergence herbicides accounted for approximately 56% of the wild oat herbicide market in 1981, 51% in 1982 and indications are that this proportion fell below 50% in 1983.

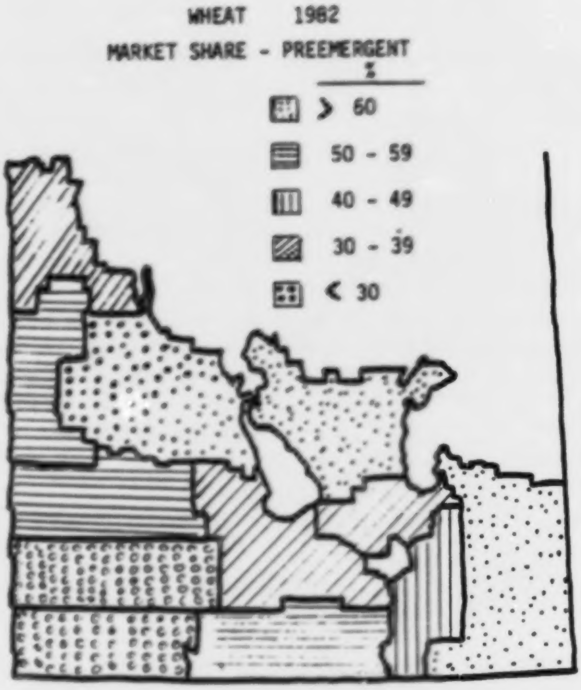

Fig. 3 Percentage of wheat hectarage utilizing preemergence wild oat control.

Not surprisingly, there are large differences in the proportion of the hectarage of various crops treated with herbicides for the control of wild oats (Table 3). Farmers obviously recognize that barley is a more competitive crop than is wheat and treat a smaller proportion of the barley hectarage for wild oats. Comparing rapeseed and flax, however, it can be seen that a higher percentage of the rapeseed hectarage is treated with wild oat herbicides. This should not be interpreted as indicating that farmers believe rapeseed is less competitive with wild oats than is flax. Rather, it is a reflection of the fact that the major herbicide utilized for control of wild oats in rapeseed, trifluralin, is also utilized for broadleaf weed control in this crop.

Table 3 Proportion of cropped hectares treated with wild oat herbicides - 1982

Crop	% Treated with wild oat herbicides
Wheat	57.3
Barley	52.0
Flax	75.9
Rapeseed	91.5
Lentils	76.7
Peas	89.2
Sunflowers	81.2

Within Manitoba, there are large regional differences in the proportion of the seeded hectarage treated with wild oat herbicides. In the case of wheat (Fig. 4) and flax (Fig. 5), the use of wild oat herbicides does correspond to the general distribution of wild oats in the province. Highest wild oat densities are found in the Parkland areas. Lower wild oat herbicide use corresponds to the lower wild oat densities generally found in the southwest region. The exceptions to this general pattern are found in the northern interlake and extreme eastern portions of the agricultural area of the province. These areas are less developed agriculturally and are often considered marginal with respect to agricultural production. Wild oats still cause serious yield losses in these regions. This information clearly demonstrates a need for additional extension efforts in this region of the province with a major emphasis on the economics of wild oat control.

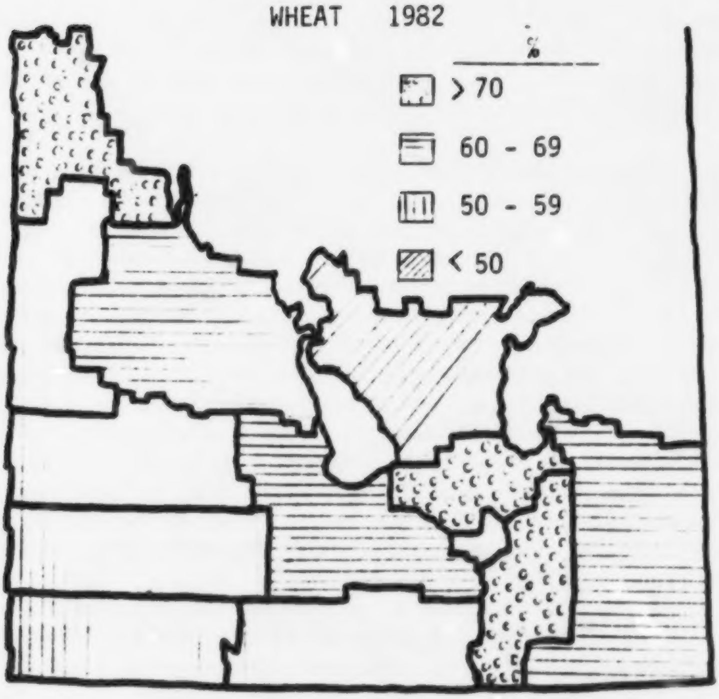

Fig. 4 Proportion of Manitoba's 1982 wheat hectarage treated with wild oat herbicides by crop district.

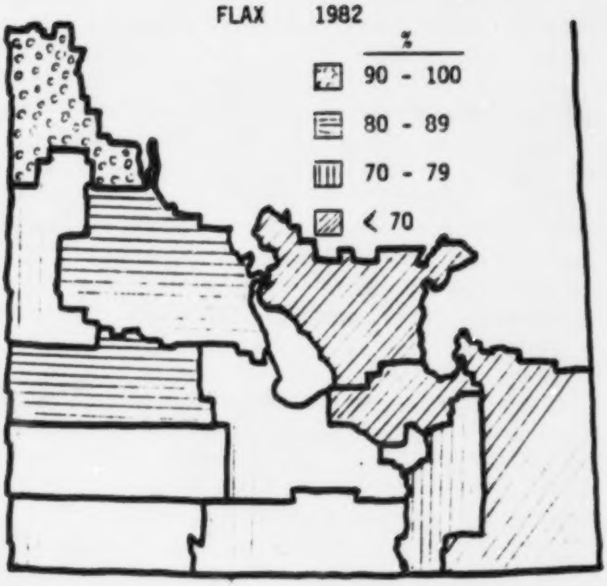
FLAX 1982
%
90 - 100
80 - 89
70 - 79
< 70

Fig. 5 Proportion of Manitoba's 1982 flax hectarage treated with wild oat herbicides by crop district.

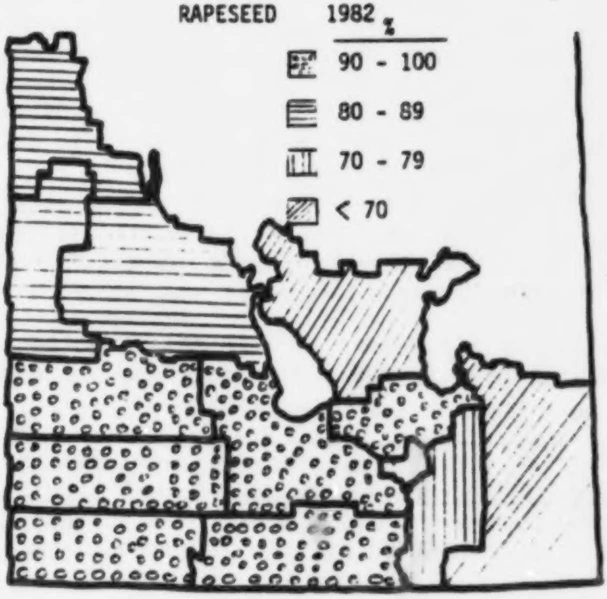
RAPESEED 1982
%
90 - 100
80 - 89
70 - 79
< 70

Fig. 6 Proportion of Manitoba's 1982 rapeseed hectarage treated with wild oat herbicides by crop district.

In rapeseed, the greatest use of wild oat herbicides is in the southwest region of the province (Fig. 6). This use pattern does not correspond to the distribution of wild oats in the province and confirms that a portion of this use can be ascribed to broadleaf weed control considerations with trifluralin. Clearly, the use of postemergence herbicides for wild oat control in rapeseed will be limited by the lack of suitable postemergence herbicides for broadleaf weed control in this crop.

It is also interesting to examine the relative popularity of various wild oat herbicides among farmers. In wheat, 29.1% of the 1982 seeded hectarage was treated with triallate, 21.3% with diclofop-methyl, 3.9% with difenzoquat, 2.2% with flamprop-methyl, and only 0.6% with barban.

In 1982, 29.3% of the seeded barley hectarage was treated with triallate, 15.1% with diclofop-methyl, 7.0% with difenzoquat, and 0.6% with barban.

A wider selection of herbicides is available for wild oat control in flax. In 1982, 21.3% of the flax hectarage was treated with trifluralin, 19.0% with asulam, 15.6% with diclofop-methyl, 9.8% with triallate, 8.2% with EPTC, 1.1% with sethoxydim and 0.2% with barban.

The predominant herbicide for wild oat control in rapeseed is trifluralin, which was used on 73.3% of the 1982 rapeseed crop in Manitoba. Another 8.8% of the seeded hectarage was treated with triallate alone (1.4%) or in combination with trifluralin (7.4%). Diclofop-methyl was used on 8.5%, barban on 0.6%, and sethoxydim on 0.2% of the rapeseed crop.

Using these herbicide-use statistics in combination with the 1982 suggested retail prices for each herbicide it is possible to calculate the total cost of wild oat herbicides used in Manitoba in 1982 (Table 4). A total of 1,949,647 hectares of wheat, barley, rapeseed, and flax were treated with wild oat herbicides at a cost to farmers of $65,121,413. The average cost of controlling wild oats in these four major crops was $33.40 per treated hectare.

Table 4 Market value of wild oat herbicides used in major cereal and oilseed crops - Manitoba (1982)

Crop	Hectares treated	$
Wheat	927,624	32,550,039
Barley	431,268	16,286,071
Flax	276,167	8,488,170
Rape	314,588	7,792,133
Total	1,949,647	65,121,413
	AVG: $33.40/ha	

If this average investment in chemical wild oat control is extrapolated to the total treated hectarage in the prairies, the cost of wild oat control is estimated to be $319,865,778 (Table 5).

Table 5 Estimated market value of wild oat herbicides used in the prairie provinces (1982)

Province	Hectares treated	$
Manitoba	2,103,752	70,265,316
Saskatchewan	4,531,385	151,348,250
Alberta	2,941,683	98,252,212
		$319,865,778

When interpreting these data, the following assumptions on which the estimate is based must be recognized:

a. the figures include the trifluralin component of triallate/trifluralin tank mixes.
b. extrapolation to Alberta and Saskatchewan assumes similar use patterns to Manitoba. In fact, use of products which will control both wild oats and green foxtail is likely to be higher in Manitoba than in the other prairie provinces.
c. suggested retail prices have been used. Farmers are often able to purchase major wild oat herbicides for less than the suggested retail price.
d. calculations are based on minimum recommended rates of the most economical formulation of each product. Higher rates (e.g., fall applications) and more expensive formulations (e.g., granular) are utilized on significant proportions of the treated hectarage.
e. these figures do not include application costs.

Interpretation of this herbicide-use information leads to the following conclusions:

1. Slower expansion of the wild oat herbicide market will lead to increasingly intense competition between manufacturers of wild oat herbicides.

   Advertising programmes accentuating product strengths (but not weaknesses) will lead to decreased credibility among farmers. Demands on government research and extension personnel will increase for information relating to product selection.

2. There will be a demand from farmers for comparison testing of wild oat herbicides both with respect to crop tolerance and wild oat control. Just as new crop varieties are tested at several locations over a number of years in order to provide a

data base on which to recommend certain varieties over others, wild oat herbicides will need to be evaluated to determine more accurately their relative performance.

3. There is a need for refinement of yield loss predictions. While competition indices have been established for wild oats growing in competition with the four major crops, these indices need to be refined to incorporate additional variables such as fertility, moisture regime, crop variety, stage of wild oat removal. These models are especially important in view of current economic difficulties which force farmers to question whether investment in wild oat herbicides to control particular wild oat infestations is warranted.

4. A major factor impeding the use of the wild oat competition indices is the lack of information available relating to the impact of limited wild oat seed production on future wild oat populations. Farmers may spray even light infestations of wild oats to prevent seed from being returned to the soil. A much closer look at the dynamics of the wild oat seed bank in the soil is required in order to provide the information needed on which to base management decisions of this type.

CONCLUSION

It is evident that tremendous improvements in the chemical technology available for controlling wild oats have taken place during the last decade. This technology has been rapidly transferred to and accepted by farmers. This is by no means the end of the challenge, however. The challenge of the next decade - a challenge every bit as great as that which was faced by the Wild Oat Action Committee a decade ago - is to ensure that the information required to enable farmers to utilize wild oat herbicides in the most efficient manner possible is generated and made available to the farming public.

THE MODE OF ACTION OF WILD OAT HERBICIDES

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ABSTRACT

There are many reports in the recent literature regarding different aspects of the mode of action of the foliage-applied wild oat herbicides diclofop, flamprop/benzoylprop/chlorfenprop, difenzoquat, and asulam, and the soil-applied herbicides triallate, EPTC, and trifluralin. However, the primary points of attack of these herbicides on biochemical or biophysical processes in the wild oat seedling or plant are not at all clear. The common thread in the foliage-applied herbicides is suppression of cell division and/or cell elongation that manifests itself as cessation of plant growth. At recommended herbicide dosages, this cessation of growth is usually temporary and competition by crop plants is essential for effective wild oat control. The action of the soil-applied herbicides is diverse and complex but also includes inhibition of cell division. The result is failure of wild oat seedlings to emerge or failure to develop beyond emergence of the coleoptile above the soil surface.

The term 'mode of action' in the title of this paper almost certainly conveys much more than the paper is going to deliver. There are strong similarities between this term and the word 'regulation' and, to put these terms in their proper perspective, I quote from Stern (1966): "'Regulation' is nowadays a catchy word. It confers sophistication on research projects and adds glitter to publications. Its frame of reference is broad and its aims are pretentious. Of all the approaches to the sweep of biological phenomena, few command so much of the air of greatness as does the pursuit of regulation. No word except for 'life' itself defines less and encompasses more than the term regulation. The activities of every living unit are regulated. To explain the regulation of some unit is, in effect, to explain its total workings. . . The presumptuousness of the title is in keeping with the colloquialisms of the times; the modesty of the subject matter is in keeping with the achievements."

The term 'mechanism of action,' partly in keeping with Moreland (1980), will be used to refer to the primary biochemical or biophysical interference that a herbicide imposes and that leads to injury or death. The term 'mode of action' will refer to the sequence of events that precedes and includes the primary response and will also include the further events that lead to plant death, after the primary response.

Since the objective of herbicide use on wild oats is to kill the plants, my concern will be with the death of these plants and the means by which disruptions to their development might result in death. Plants have a remarkable ability to recover and regenerate following injury and, therefore, one must wonder how an applied chemical can so disorganize these systems that plant death occurs. Sometimes, we, as weed scientists, complain loudly and long about our ignorance of the processes and primary actions that are involved in bringing about plant death, but this ignorance is not unique to death from herbicides. Even for such a relatively simple process as death resulting from water stress, the process or structure that is affected primarily has not been clearly defined (Kefford, 1976).

If we had a neat unifying theory for the regulation of normal plant development, then perhaps we could pinpoint within this theory the loci at which disruptions are induced by each particular class of herbicides. However, no good unifying theory for normal development exists; nor has a unifying theory for mechanisms of development-disrupting herbicides been achieved through any other approach. Kefford lists a series of means by which herbicides might disrupt development, and the evidence that he includes shows that the classes of herbicides differ in the means by which they initiate such disruptions. He also states that "nothing, however, can be offered to cover the gap between a disruption of development and the common outcome of herbicidal action, degenerative injury and plant death."

There is a vast amount of literature that deals with the mode of action of herbicides, and a substantial portion of this literature deals with wild oat herbicides, both soil-applied and foliage-applied herbicides. I cannot hope, in the time allotted to me, to do complete justice to all the literature that exists regarding the mode of action of wild oat herbicides so I shall have to put some limitations on the amount of subject matter to be covered. Other speakers in this symposium have already dealt with the history of development of wild oat herbicides and will deal with the effect of environmental factors and with the interaction of wild oat herbicides with each other and with herbicides used to control other weeds. I shall confine my comments, therefore, to what happens to the wild oat herbicides after they have been deposited on the leaves or near the coleoptile or the roots of wild oat seedlings. For each herbicide to be discussed, I shall refer, with unequal emphasis, to penetration and absorption, translocation, injury symptoms, site and mechanism of action, and to metabolism of the herbicides. Selectivity of the herbicides will not be dealt with in its own right but some comments will be made about it in relation to the five categories indicated above.

In the group of foliage-applied herbicides I shall refer to barban, diclofop, the flamprop/benzoylprop/chlorfenprop complex, difenzoquat, and asulam. In the category of soil-applied herbicides, I shall make reference to triallate, EPTC, and trifluralin.

All of the selective wild oat herbicides behave as systemic herbicides, in the sense that their modes of action generally are associated with disruption of the normal functioning of one or more physiological or metabolic plant processes. It appears safe to make the generalized statement that translocation of all foliage-applied wild oat herbicides takes place very slowly and in very small quantities. It is important, therefore, that the herbicides be deposited as close to the site of their ultimate action as is practically possible (e.g., Coupland et al., 1978; Pallett, 1980; Walter and Bischof, 1976). The action of most of the foliage-applied herbicides appears to consist of a direct inhibition of cell division and cell elongation processes, and usually it is not clear which of these two processes is affected most seriously. Most of the statements that appear in the literature regarding effects of the herbicides on one or the other of these processes are not based on particularly clear evidence and seem to represent the opinions of the authors more than the conclusions of definitive experiments. It is likely, in fact, that in most instances both types of processes are affected, and that it is not really possible at this point to make precise distinctions between the effects on the two processes.

There are a few reports in the literature that describe the effects of wild oat herbicides on various plant metabolic processes. Chow (1982), for example, studied the response of wild oat to five foliage-applied herbicides. He reported that chlorophyll content was reduced by the application of diclofop and difenzoquat and that photosynthate translocation from the leaves to the roots was reduced only by treatment with diclofop, difenzoquat, or flamprop. Each of the herbicides evidently affected more than one physiological function and/or biochemical process in wild oats. It is unlikely, however, that any of these reactions represent primary responses or points of attack of the herbicides investigated. Rather, it is likely that all of the responses are secondary responses which have little to do with the primary site of action of the herbicides.

DICLOFOP

Diclofop is applied as the methyl ester and is hydrolyzed to the parent acid form in both tolerant and susceptible plant species. Both forms of the herbicide are toxic to certain grass species in the seedling stage of growth. The herbicide causes two injury effects when applied to the foliage of wild oats: (i) chlorosis and necrosis in leaf tissue, possibly as a result of membrane damage, and (ii) inhibition of cell division in meristem tissue. It has been suggested that the methyl ester is the toxicant that disrupts membrane integrity and is responsible for the chlorosis and necrosis of leaf tissue, with chloroplasts showing the most damage (Brezeanu et al., 1976). The parent acid is thought to be the toxicant responsible for inhibition of meristematic activity and perhaps of root growth (Shimabukuro et al., 1979).

Following foliage application of diclofop, there was a rapid increase in the permeability of leaf cell membranes in wild oats and barley, before the appearance of visible injury, such as discoloration or necrotic areas in leaf tips (Crowley and Prendeville, 1979). In wheat, such increases in permeability occurred only after 48 hours, compared to 12 hours for the other two species. Treated wild oat plants developed chlorosis over the entire leaf blade, and leaves became necrotic 7 days after spraying (Hoerauf and Shimabukuro, 1979). In wheat plants, discrete chlorotic areas developed only where the herbicide contacted the youngest leaves (second or third leaf), and no visible injury occurred in new growth that appeared after treatment. Ultrastructural effects resembled those that a normal parenchyma cell undergoes as it senesces (Brezeanu et al., 1976); Davis and Brezeanu, 1979). Chloroplasts were the organelles most affected in both species (wild oat and wheat). Cellular changes ranging from slight to complete destruction of the cytoplasm were observed in treated leaves. Growth inhibition consisted mostly of reduced internode elongation.

The effectiveness of diclofop on wild oats is reduced considerably when the plants are exposed to soil moisture stress (Dortenzio and Norris, 1980; Akey and Morrison, 1983); the reasons for this effect are not clear.

Very little translocation of diclofop and/or its metabolites occurred from leaves to roots (Brezeanu et al., 1976). There is good evidence, however, that diclofop also is active in inhibiting plant growth following root uptake, particularly if soil moisture is high (Mulder and Nalewaja, 1979; Crowley et al., 1978).

Diclofop was taken up readily by roots of wheat and wild oats, though uptake by wild oats was less than half that by wheat. Less than 5% of the absorbed herbicide was translocated to the shoot (Jacobson and Shimabukuro, 1982). Both the ester and the parent acid were translocated. Crowley et al. (1978) concluded that root exposure caused greater toxicity than shoot exposure. Root-applied herbicide enhanced the development of adventitious roots in the shoots of wild oats and barley, and resulted in a sharp increase in shoot uptake of calcium. Shoot-applied herbicide inhibited both these processes.

Morrison et al. (1981) reported that in wild oat roots, 24 hours after treatment with diclofop, severe damage occurred to tissues within the developing central cylinder, close to the root apex. These authors concluded that "the available evidence indicates that diclofop inhibits the onset of mitosis by directly or indirectly arresting the progression of the cell during interphase."

Selectivity of diclofop-methyl between wild oats and other species appears to be related almost exclusively to differential rates of metabolism of the herbicide (Boldt and Putnam, 1981). Rapid hydrolysis of the ester to the parent acid took place in both wild oats and wheat, but neither compound was accumulated in the tissues of these species (Shimabukuro et al., 1979). It is probable that the irreversible conjugation and, therefore, detoxification of the herbicide in wheat, but not in wild oats, is the primary factor in bringing about its selectivity.

Barley, wild oat, and green foxtail were 2, 190, and 1090 times more sensitive, respectively, than wheat to diclofop-methyl applied at the two-leaf stage of growth (Todd and Stobbe, 1977). Wild oat was 320 times more sensitive than wheat to root-applied diclofop-methyl (cited in Anderson, 1983). Cultivated oats metabolized the ester of diclofop somewhat less rapidly than wild oats but the metabolites formed were almost identical (Dusky et al., 1982).

Physiological effects such as a reduction in carbon dioxide utilization (Shimabukuro et al., 1978) or of state three respiration (Cohen and Morrison, 1981) are almost certainly secondary responses that have little to do with the direct mechanism of action of the herbicide. Shimabukuro et al. (1978) suggested that "diclofop-methyl functions as a strong auxin antagonist, while the metabolite, diclofop, inhibits root growth and development by another mechanism. The herbicidal effect of diclofop-methyl may be the net effect of two biologically active forms of the compound, each with a different mode of action, acting at different sites within a susceptible plant."

In research dealing with antagonism of the activity of diclofop by phenoxy herbicides, Olson et al. (1981) concluded that diclofop ester was a three-fold stronger inhibitor of oat coleoptile growth than the parent acid. It is not clear, however, what the significance of this observation is regarding the observed antagonism or regarding the mechanism of action diclofop.

Hall et al. (1982) concluded that, contrary to the reports of Olson and Nalewaja (1982) and Todd and Stobbe (1977), the addition of MCPA or 2,4-D is not biologically significant in reducing diclofop or diclofop-methyl accumulation in the root and shoot apex of wild oat. They concluded (Hall et al., 1982) that the observed antagonism appeared to occur at the apical meristem, and had little to do with the change in the pattern of diclofop translocation.

FLAMPROP/BENZOYLPROP/CHLORFENPROP

Herbicides in the flamprop/benzoylprop/chlorfenprop complex are conspicuous for the lack of attention they have received in two recent textbooks published in North America. I can only assume that this lack of attention results from the lack of or delay in commercial development of these herbicides in the United States where both these books were written. There is extensive literature on these herbicides in Canadian and European journals.

The typical response of wild oat plants treated with these herbicides is that they stop elongation and remain stunted, at least for a time. In the absence of competition by crop plants, the wild oat plants can recover and resume growth and ultimately produce seeds. Crop competition, therefore, plays an essential role in a wild oat control programme that involves the use of these herbicides (Sharma and Vanden Born, 1983).

All three of the herbicides are applied to the foliage of wild oat, particularly in crops of wheat but also, with one type of ester, in barley. They are formulated as esters which are hydrolyzed quickly upon entry of the leaf tissue. There is good evidence, in fact, that the activity of the herbicides in each instance is dependent on their degradation to the biologically active parent acid (Jeffcoat and Harries, 1973). Hydrolysis of the esters takes place most rapidly in oat or wild oat and is slowest in wheat. The acid, unlike the ester, showed some movement via the phloem from the leaves to the stem where it inhibited stem elongation through an effect on cell expansion. Observations by Morrison et al. (1979) include a severe reduction in the growth of leaves and internodes of wild oat plants treated with benzoylprop. Cell division as well as cell elongation was inhibited.

Most of the literature on this group of herbicides deals with their metabolism in plants and the role this metabolism plays in selectivity. Tolerance of wheat results not only from a slow hydrolysis of the ester but also is aided by rapid conjugation of the parent acid to a non-toxic form. In essence, therefore, the accumulation of the parent acid to toxic levels is prevented in wheat but not in wild oats. An esterase enzyme presumed to be responsible for the hydrolysis has been extracted from wild oat tissue and partially purified (Hill et al., 1978; Venis, 1982).

The rate of hydrolytic degradation of flamprop-methyl is said to be comparable to that of benzoylprop-ethyl but the more active flamprop acid that is produced accounts for increased herbicide efficacy (Jeffcoat et al., 1977).

Detoxification of the active acid molecule is by conjugation in wheat (Roberts, 1977). According to Pillmoor et al. (1982), conjugation of flamprop has a marked effect on mobility of the herbicide within leaf tissue. One group of conjugates could be almost completely washed from the tissue following disruption of the membranes by a freeze/thaw procedure, indicating that immobility of this group was due to partition behind an impermeable membrane. The other group of conjugates could only be partially removed by this procedure, the remainder being released by extraction with an organic solvent. The authors state that, "The present results provide clear proof that conjugation of flamprop produces dramatic changes in its mobility, with the conjugates being very strongly retained by the symplast. In the intact plant the conjugates would be expected to be equally as strongly retained by the cell in which they are formed and therefore be unavailable for transport."

The methyl ester of flamprop is suitable for control of wild oats in wheat but causes considerable injury to barley. The isopropyl ester, on the other hand, is suitable for control of wild oats in barley, with selectivity and metabolism following the same patterns as those described for flamprop-methyl (Roberts, 1977; Jeffcoat and Harries, 1975).

The last herbicide in the series, chlorfenprop-methyl, has received much less attention in the literature (Andreev and Amrhein, 1976; Fedtke and Schmidt, 1977; Gauvrit, 1983; Collet and Pont, 1978). According to one report (Fedtke and Schmidt, 1977), the herbicide is hydrolyzed completely as soon as it penetrates the leaf in sensitive as well as in resistant plants and the parent acid is presumed to be the active compound. The ester form caused a loss of membrane integrity in potato tuber mitochondria (Gauvrit, 1983) but the parent acid and its cysteine conjugate had no such effects and, therefore, membrane effects were not considered to be a mechanism of phytotoxic action of this herbicide. In an earlier report, Andreev and Amrhein (1976) concluded that the free acid was less effective than the ester in inhibiting auxin-mediated cell responses in coleoptiles of oats and corn. The details of the precise mechanism, therefore, are not clear.

DIFENZOQUAT

Difenzoquat is a foliage-applied wild oat herbicide for use in barley and some varieties of wheat. The herbicide is a water-soluble material and is much more sensitive to rain falling on the plants soon after spraying than the herbicides described so far. Nevertheless, according to Caseley and Coupland (1980), small amounts of rain do not necessarily reduce the performance of difenzoquat because the spray deposit is removed primarily from the leaf blade while in the more responsive ligule/leaf sheath area the herbicide remains in solution.

Penetration of difenzoquat in wild oats and barley takes place rapidly (Sharma et al., 1976). The rate of penetration was, in fact, much greater when the herbicide was applied to the inner surface of the leaf sheath than when the leaf blade and other sheath areas were treated (Caseley and Coupland, 1980). Translocation of herbicide from spot applications made at the mid-point of wild oat leaves resulted in necrosis of the leaf area above the point of application (Friesen and Litwin, 1975). Translocation of radioactive herbicide from such application also occurred in an acropetal direction. Some translocation also took place to the roots but a large proportion of the absorbed radioactivity remained near the treated leaf area. No evidence of metabolism of difenzoquat was found for up to 15 days after treatment. Merritt (1982) also reported that the herbicide was more active when applied to the base of leaves and to younger leaves than to leaf tips in older leaves. In most cases, reduced activity of difenzoquat was related to increased localized scorch and reduced movement of herbicide from the treated region. Clearly, surfactants and other additives to the difenzoquat formulation play an important role in the effectiveness of this herbicide because of the influence they have on entry of the herbicide into the leaf tissue. Taylor et al. (1982) also concluded that additional oil/surfactant improved the spreading and wetting properties of sprays which, in turn, reduced localized contact injury and made possible increased uptake and translocation of the herbicide. Pallett (1982) has suggested that the contact action of difenzoquat is due to a "weak paraquat-type activity." He reported that difenzoquat caused swelling of the chloroplasts with subsequent disorganization of the thylakoid system accompanied by disruption of other cellular components. Earlier, Friesen and Litwin (1975) reported that shoot tips of treated wild oat plants showed extensive chromosome clumping and shrinking and necrosis of the cells. Pallett (1982) quotes other authors as saying that, "The primary herbicidal action of difenzoquat has been established as an interference with the division and elongation of cells in the apical meristem," but the evidence for such a statement is not particularly clear.

Cohen and Morrison (1982) reported that root-applied difenzoquat caused more pronounced inhibition of potassium ion absorption in excised seedling roots of wild oat than in similar roots of barley or wheat and concluded that, while difenzoquat did not affect the passive permeability properties of the plasma membrane of wild oat root cells, it did interfere directly with the process of active ion transport across such plasma membranes. Pallett and Caseley (1980) suggested that differences in sensitivity of spring wheat cultivars to difenzoquat might be attributed to differential inhibition of DNA synthesis, but there is no evidence to indicate that selectivity between wild oats and barley or wheat could be attributed to such a factor.

BARBAN

Barban is another postemergence herbicide used exclusively to control wild oat. For this herbicide, much more so than the ones mentioned so far, the time of application or, rather, the stage of growth of the wild oat plant, is critical to obtain effective control. Barban must be applied at the two-leaf stage of wild oat, from the appearance of the second leaf until the appearance of the third leaf. Earlier or later applications will give poor control. In addition, the appropriateness of the stage is influenced by the growing conditions under which the plant reaches this particular growth stage.

Substantial leaf absorption of the barban took place within a few hours but absorption continued for at least a week (Foy, 1961, cited in Ashton and Crafts, 1981). Barban was absorbed and translocated in small amounts when applied to the upper surface of the first leaf and the greatest movement appeared to be in the transpiration stream toward the tip of the leaf. Much larger amounts were absorbed and translocated when barban was applied to the axil of the first leaf. Foy's results contradict those of Kobayashi and Ishizuka (1974) who reported that the rate of absorption of barban by intact shoots of oats was much higher than for wheat. Barban caused swelling and distortion of the shoot apex in wild oat (Dubrovin, 1959, cited in Ashton and Crafts, 1981); the cells were large, contained numerous groups of chromosomes, and the nuclear membranes as well as the nucleoli were absent. Of the inhibitory effects on several biochemical processes, its interference with nucleic acid metabolism may well be most closely associated with its effect on cell division and growth (Klingman and Ashton, 1982, page 175). The herbicide appears to behave as a mitotic poison, at least for a time. Here also, competition by the crop is essential for an extended period of suppression of wild oat plant growth.

Effects of barban on oxidative phosphorylation, nucleotide metabolism, metabolism of RNA, protein and nucleoproteins, various mitochrondrial reactions, and others have been reported (Ashton and Crafts, 1981, page 193) but with respect to the prime mechanism of action of the herbicide, nothing appears to be clearly established.

With respect to selectivity, Kobayashi and Ishizuka (1974) found some differences in effects on protein and RNA synthesis in wheat and wild oat seedlings. Neidermyer and Nalewaja (1974) reported a greater margin of selectivity between wild oats and wheat at 27° and 21°C than at 16° and 10°C. More details of this temperature effect on barban toxicity were reported by Miller _et al._ in 1978.

Experiments reported by Chang _et al._ (1974) and Miller _et al._ (1978) indicated that cultivated oats could be protected almost completely from the phytotoxic effect of barban by applying NA (1,8-naphthalic anhydride) as a seed dressing, thus allowing the use of barban for the selective control of wild oats in oat crops. Additional results regarding such use of an antidote were reported by Thiessen _et al._ in 1980. None of these findings, however, has resulted in practical applications to date.

Shimabukuro et al. (1976) reported that differential sensitivity of wild oat and wheat was highest when barban was applied to the coleoptile. The coleoptile was said to act as a "physical and physiological barrier to reduce the concentration of free barban in the stem section where the sensitive meristematic sites are located." The practical significance of this observation, however, is not clear.

The evidence for precise designation of the prime point of attack of barban is still wanting.

ASULAM

Asulam is used to control wild oats in flax, and is applied to the foliage. Available evidence indicates that selectivity between the two species depends to a large extent on the differential retention and subsequent absorption and penetration of asulam in the two species (Sharma et al., 1978). No differences in metabolism of asulam in the two species have been reported. More recent findings of Stephen et al. (1980) and Veerasekaran et al. (1981) indicated that asulam may bring about its phytotoxic effect by an inhibition of the biosynthesis of folic acid and that this inhibition results in the impairment of biological methylations and hence an inhibition of protein and nucleic acid synthesis.

It appears, then, that the main mechanism of action of asulum also is one of interference with cell division. In onion root tips, the herbicide has caused mitotic irregularities including arrested metaphase and anaphase (Ashton and Crafts, 1981, page 183).

TRIFLURALIN

Trifluralin is used in rapeseed, sunflower, and mustard for control of wild oats and other grass and broadleaved weed species. Control of wild oats has often been incomplete, particularly in soils with fairly high organic matter content.

Numerous papers in the literature deal with the behaviour of trifluralin in soil and the response of a variety of plant species to this herbicide under many different conditions. Little or none of the literature on trifluralin, however, appears to apply directly to wild oats; all of the work has been done with other species for the control of which this herbicide is used. Germination, defined as emergence of the radicle from the seed, does not usually appear to be inhibited by trifluralin, but weed seedlings frequently do not emerge from soil treated with this herbicide. Growth inhibition appears to result largely from an initial limitation of root growth, especially an inhibition of lateral or secondary roots. The roots that do develop are thickened and stubby (Ashton and Crafts, 1981, page 201). The inhibition of root growth has a direct effect and the most observable symptom is the inhibition of lateral root formation. The inhibition of shoot growth following root absorption is probably a secondary effect caused by limited root growth. However, when the herbicide is absorbed by the shoot it inhibits shoot growth directly. Trifluralin interferes with cell division and appears to act by binding to tubulin which, in turn, prevents tubulin assembly into microtubules. Trifluralin and other dinitroaniline herbicides interfere with microtubule structure and function and, since microtubules are functional elements of the spindle apparatus, herbicide treatment causes an interruption of spindle formation. A detailed review has been published by Parka and Soper (1977).

Most evidence suggests that trifluralin is readily absorbed by roots and by shoots but that it is translocated poorly from one organ to the other. Entrance into roots appears to be difficult if the epidermis is intact and much trifluralin can be absorbed on the outside surface of the root tissue (Strang and Rogers, 1971).

The dinitroaniline herbicides alter several biochemical processes in higher plants but it is not at all clear what relationship these effects have to the primary site of action of the dinitroaniline herbicides.

TRIALLATE

Of the soil-applied herbicides available for wild oat control, triallate is most widely used. Triallate is applied to the soil, mixed with the soil, and is absorbed by the young shoot of the wild oat plant as it passes through the layer of treated soil. There is a generally held belief that triallate is dispersed through the soil in a vapor form, although findings reported by Ashford (1975) have cast doubt on this belief. In his work, there was no significant effect on the growth of oat seedlings if triallate granules were as much as 1 cm distant from the seed. Growth inhibition from vapor of triallate formulation applied to the soil increased as soil moisture content and soil temperature increased (Miller and Nalewaja, 1976). The site of effective vapor action was considered to be below the soil surface.

The major effect of triallate on wild oats appeared to be on cell elongation of foliar material enclosed in the coleoptile (Billett and Ashford, 1978). At high rates, the leaves may not emerge at all; at lower rates they may emerge but remain longitudinally rolled or emerge through the base of the coleoptile. Such a leaf may elongate to form a loop with its tip within the coleoptile tip. In experiments reported by McKercher et al. (1975), triallate stimulated coleoptile extension and reduced the length of the primary leaf but had no effect on mesocotyl development, in wild oat seedlings grown in a growth cabinet.

Absorption of triallate is mainly through the coleoptile and, by making droplet applications on oat seedlings, Parker (1963) demonstrated that absorption in the region 10 to 15 mm above the coleptile node resulted in maximum inhibition of growth, in wild oats and also in barley and wheat. When triallate was applied to root tips, there was very little translocation (Nalewaja, 1968) but when diallate was applied to the coleoptile tips of barley, wheat, and wild oat seedlings there was movement of radioactivity through the coleoptiles into the roots. No identification was provided of the radioactive materials detected.

Banting (1970) reported a variety of mitotic abnormalities in wild oat seedlings treated with triallate and especially with diallate. The number of cell divisions decreased as the concentration of the herbicide was increased. Shoot tissues of both wild oat and wheat were more sensitive than root tissues. However, shoot growth inhibition occurred in both species at concentrations that did not affect mitosis. Thus, mitotic damage from either chemical appeared to be secondary to cell elongation and expansion as part of a mechansim of action.

The mechanism of action of triallate and of thiocarbamates in general has been attributed to a wide variety of metabolic pathways (Ashton and Crafts, 1981). The primary effect, however, appears to be an interference with cell elongation or expansion, particularly in the young growing leaves inside the coleoptile sheath.

Normal plant metabolism is altered in a variety of ways by triallate and other thiocarbamate herbicides but it is not possible to be certain about the relative importance of these various processes to the herbicide action. The inhibition of lipid synthesis appears to be the most sensitive, however, and has been studied the most. Aside from the reduction of synthesis of epicuticular lipids on leaves by as much as 80% after triallate treatment (for example, Davis and Dusbabek, 1973), the relationship of such inhibition of lipid biosynthesis to reduced cell division and expansion is not clear.

Evidence on the mechanism of selectivity is very limited. Selectivity appears to be related primarily to the stage of growth and probably to the location and rate of cell division in the tissue that is most readily exposed to triallate either in liquid or in vapor form.

EPTC

Most of the statements regarding triallate also apply to EPTC, another thiocarbamate herbicide used incidentally for wild oat control but with a much broader weed spectrum than the herbicides that have been discussed so far. In western Canada, EPTC is registered for use in sunflowers. EPTC is very similar to triallate in its soil and root absorption behaviour except that it is considerably more volatile than triallate and appears to be translocated more readily through plants. There is some doubt about this translocation, however, because the identity of the radioactive compounds translocated has not been clearly established (Ashton and Crafts, 1981, pages 308-309).

With respect to carbamate herbicides, Kirkwood (1976) states, with appropriate hedging, "It seems likely that the inhibition of oxidative phosphorylation by carbamate herbicides is not the primary site of action, but rather that inhibition of certain biosynthetic reactions such as RNA and protein synthesis may be in part an indirect effect of interference with energy production."

CONCLUSION

Confucius reportedly said "What we know may be interesting but what we don't know is fascinating." If we continue to be fascinated with our ignorance of precisely how it is that wild oat herbicides kill the unwanted plants, then perhaps one day we shall know.

REFERENCES

Akey, W.C., and Morrison, I.N. 1983. Effect of moisture stress on wild oat (Avena fatua) response to diclofop. Weed Sci. 31: 247-253.

Anderson, W.P. 1983. Weed science: Principles. Second ed. West Publ. Co. St. Paul, New York, Boston, Los Angeles, San Francisco. 655 p.

Andreev, G.K., and Amrhein, N. 1976. Mechanism of action of the herbicide 2-chloro-3-(4-chlorophenyl) propionate and its methyl ester: Interaction with cell responses mediated by auxin. Physiol. Plant. 37: 175-182.

Ashford, R. 1975. Triallate granule spacing effect on oat. Weed Sci. 23: 470-472.

Ashton, F.M., and Crafts, A.S. 1981. Mode of action of herbicides. Second ed. Wiley-Interscience. New York. 525 p.

Banting, J.D. 1970. Effect of diallate and triallate on wild oat and wheat cells. Weed Sci. 18: 80-84.

Billett, D., and Ashford, R. 1978. Differences in the phytotoxic response of wild oats (Avena fatua) to triallate and trifluralin. Weed Sci. 26: 273-276.

Boldt, P.F., and Putnam, A.R. 1981. Selectivity mechanisms for foliar applications of diclofop-methyl. II. Metabolism. Weed Sci. 29: 237-241.

Brezeanu, A.G., Davis, D.G., and Shimabukuro, R.H. 1976. Ultrastructural effects and translocation of methyl 2-(4-(2,4-dichlorophenoxy)phenoxy) propanoate in wheat (*Triticum aestivum*) and wild oat (*Avena fatua*). Can. J. Bot. 54: 2038-2048.

Caseley, J.C., and Coupland, D. 1980. Effect of simulated rain on retention, distribution, uptake, movement and activity of difenzoquat applied to *Avena fatua*. Ann. Appl. Biol. 96: 111-118.

Chang, F.Y., Stephenson, G.R., Anderson, G.W., and Bandeen, J.D. 1974. Control of wild oats in oats with barban plus antidote. Weed Sci. 22: 546-548.

Chow, P.N.P. 1982. Wild oat (*Avena fatua*) herbicide studies: I. Physiological response of wild oat to five postemergence herbicides. Weed Sci. 30: 1-6.

Cohen, A.S., and Morrison, I.N. 1981. *In vitro* sensitivity of wheat and oat mitochondria to the selective herbicide, diclofop-methyl. Pestic. Biochem. Physiol. 16: 110-119.

Cohen, A.S., and Morrison, I.N. 1982. Differential inhibition of potassium ion absorption by difenzoquat in wild oat and cereals. Pestic. Biochem. Physiol. 18: 174-179.

Collet, F.C., and V. Pont. 1978. Le role de la cysteine dans la detoxification d'un herbicide. C.R. Acad. Sci., Serie D 286: 681-684.

Coupland, D., Taylor, W.A., and Caseley, J.C. 1978. The effect of site of application on the performance of glyphosate on *Agropyron repens* and barban, benzoylprop-ethyl and difenzoquat on *Avena fatua*. Weed Res. 18: 123-128.

Crowley, J., O'Donovan, J.T., and Prendeville, G.N. 1978. Phytotoxicity of soil-applied dichlorfop methyl and its effect on uptake of ^{45}Ca in wild oats, barley and wheat. Can. J. Plant Sci. 58: 395-399.

Crowley, J., and Prendeville, G.N. 1979. Effect of dichlofop-methyl on leaf-cell membrane permeability in wild oat, barley and wheat. Can. J. Plant Sci. 59: 275-277.

Davis, D.G., and Brezeanu, A. 1979. An ultrastructural study of *Triticum monococcum* cell suspension cultures during aging and after treatment with the herbicide diclofop-methyl (methyl-2-(4-(2',4'-dichlorophenoxy)phenoxy)propanoate). Can. J. Bot. 57: 2006-2020.

Davis, D.G., and Dusbabek, K.E. 1973. Effect of diallate on foliar uptake and translocation of herbicides in pea. Weed Sci. 21: 16-18.

Dortenzio, W.A., and Norris, R.F. 1980. The influence of soil moisture on the foliar activity of diclofop. Weed Sci. 28: 534-539.

Dusky, J.A., Davis, D.G., and Shimabukuro, R.H. 1982. Metabolism of diclofop-methyl in cell culture of Avena sativa and Avena fatua. Physiol. Plant. 54: 490-494.

Fedtke, C., and Schmidt, R.R. 1977. Chlorfenprop-methyl: its hydrolysis in vivo and in vitro and a new principle for selective herbicidal action. Weed Res. 17: 233-239.

Friesen, H.A., and Litwin, O.B. 1975. Selective control of wild oats in barley with AC 84777. Can. J. Plant Sci. 55: 927-934.

Gauvrit, C. 1983. Action of chlorfenprop-methyl on membrane integrity in plant mitochondria. Weed Res. 23: 85-89.

Hall, J.C., Edgington, L.V., and Switzer, C.M. 1982. Translocation of different 2,4-D, bentazon, diclofop, or diclofop-methyl combinations in oat (Avena sativa) and soybean (Glycine max). Weed Sci. 30: 676-682.

Hill, B.D., Stobbe, E.H., and Jones, B.L. 1978. Hydrolysis of the herbicide benzoylprop-ethyl by wild oat esterase. Weed Res. 18: 149-154.

Hoerauf, R.A., and Shimabukuro, R.H. 1979. The response of resistant and susceptible plants to diclofop-methyl. Weed Res. 19: 293-299.

Jacobson, A., and Shimabukuro, R.H. 1982. The absorption and translocation of diclofop-methyl and amitrole in wheat and oat roots. Physiol. Plant. 54: 34-40.

Jeffcoat, B., and Harries, W.N. 1973. Selectivity and mode of action of ethyl-2-(N-benzoyl-3,4-dichloroanilino)propionate in the control of Avena fatua in cereals. Pestic. Sci. 4: 891-899.

Jeffcoat, B., and Harries, W.N. 1975. Selectivity and mode of action of flamprop-isopropyl, isopropyl (±)-2-[N-(3-chloro-4-fluorophenyl) benzamido] propionate, in the control of Avena fatua in barley. Pestic. Sci. 6: 283-296.

Jeffcoat, B., Harries, W.H., and Thomas, D.B. 1977. Factors favouring the choice of flamprop-methyl, methyl (±)-2-[N-(3-chloro-4-fluorophenyl)benzamido)propionate for the control of Avena species in wheat. Pestic. Sci. 8: 1-12.

Kefford, N.P. 1976. Dislocation of developmental processes, p. 427-442. In Audus, L.J., (ed.), Herbicides: Physiology, Biochemistry, Ecology. Vol. 2. Academic Press, New York.

Kirkwood, R.C. 1976. Action on respiration and intermediary metabolism, p. 444-492. In Audus, L.J. (ed.), Herbicides: Physiology, Biochemistry, Ecology. Vol. 2. Academic Press, New York.

Klingman, G.C., and Ashton, F.M. 1982. Weed science: Principles and practices. Wiley-Interscience. New York. 449 p.

Kobayshi, K., and Ishizuka, K. 1974. Selective herbicidal action of barban on oat and wheat plants. Weed Sci. 22: 131-135.

McKercher, R.B., Ashford, R., and Morgan, R.E. 1975. Effects of triallate on wild oat grown in a growth chamber. Weed Sci. 23: 283-285.

Merritt, C.R. 1982. The influence of form of deposit on the phytotoxicity of difenzoquat applied as individual drops to Avena fatua. Ann. Appl. Biol. 101: 517-525.

Miller, S.D., and Nalewaja, J.D. 1976. Phytotoxicity of tiallate vapours to wild oat. Weed Sci. 24: 134-136.

Miller, S.D., Nalewaja, J.D., Dobrzanski, A., and Pudelko, J. 1978. Temperature effect on barban phytotoxicity. Weed Sci. 26: 132-134.

Moreland, D.E. 1980. Mechanisms of action of herbicides. Ann. Rev. Plant Physiol. 31: 597-638.

Morrison, I.N., Hill, B.D., and Dushnicky, L.G. 1979. Histological studies on the effects of benzoylprop ethyl and flamprop methyl on growth and development of wild oats. Weed Res. 19: 385-393.

Morrison, I.N., Owini, M.G., and Stobbe, E.H. 1981. Effects of diclofop on growth, mitotic index and structure of wheat (Triticum aestivum) and wild oat (Avena fatua) adventitious roots. Weed Sci. 29: 426-432.

Mulder, C.E.G., and Nalewaja, J.D. 1979. Influence of moisture on soil-incorporated diclofop. Weed Sci. 27: 83-87.

Nalewaja, J.D. 1968. Uptake and translocation of diallate in wheat, barley, flax and wild oat. Weed Sci. 16: 309-312.

Neidermyer, R.W., and Nalewaja, J.D. 1974. Barban selectivity for wild oat in wheat. Weed Sci. 22: 476-480.

Olson, W.A., and Nalewaja, J.D. 1982. Effect of MCPA on ^{14}C-diclofop uptake and translocation. Weed Sci. 30: 59-63.

Olson, W.A., Nalewaja, J.D., Schroeder, G.L., and Duysin, M.E. 1981. Diclofop and MCPA influence on coleoptile growth. Weed Sci. 29: 597-600.

Pallett, K.E. 1980. The mechanisms of activity and selectivity of the wild oat herbicides. Brit. Crop Prot. Conf.-- Weeds Proc. 3: 843-854.

Pallett, K.E. 1982. The contact activity of difenzoquat in two United Kingdom spring wheat cultivars. Weed Res. 22: 329-335.

Pallett, K.E., and Caseley, J.C. 1980. Differential inhibition of DNA synthesis in difenzoquat-tolerant and susceptible United Kingdom spring wheat cultivars. Pestic. Biochem. Physiol. 14: 144-152.

Parka, S.J., and Soper, A.F. 1977. The physiology and mode of action of the dinitroaniline herbicides. Weed Sci. 25: 79-87.

Parker, C. 1963. Factors affecting the selectivity of 2,3-dichlorallyl diisopropylthiolcarbamate (diallate) against Avena spp. in wheat and barley. Weed Res. 3: 259-276.

Pillmoor, J.B., Roberts, T.R., and Gaunt, J.K. 1982. Compartmentation of flamprop and its metabolites in leaf slices of oats. J. Exp. Bot. 33: 919-928.

Roberts, T.R. 1977. The metabolism of the herbicide flamprop-methyl in wheat. Pestic. Sci. 8: 463-472.

Sharma, M.P., Vanden Born, W.H. 1983. Crop competition aids efficacy of wild oat herbicides. Can. J. Plant Sci. 63: 503-507.

Sharma, M.P., Vanden Born, W.H., Friesen, H.A., and McBeath, D.K. 1976. Penetration, translocation, and metabolism of ^{14}C-difenzoquat in wild oat and barley. Weed Sci. 24: 379-384.

Sharma, M.P., Vanden Born, W.H., and McBeath, D.K. 1978. Spray retention, foliar penetration, translocation and selectivity of asulam in wild oats and flax. Weed Res. 18: 169-173.

Shimabukuro, M.A., Shimabukuro, R.H., Nord, W.S., and Hoerauf, R.A. 1978. Physiological effects of methyl 2-[4-(2,4-dichlorophenoxy)phenoxy] propanoate on oat, wild oat, and wheat. Pestic. Biochem. Physiol. 8: 199-207.

Shimabukuro, R.H., Walsh, W.C., and Hoerauf, R.A. 1976. The role of coleoptile on barban sensitivity between wild oats and wheat. Pestic. Biochem. Physiol. 6: 115-125.

Shimabukuro, R.H., Walsh, W.C., and Hoerauf, R.A. 1979. Metabolism and selectivity of diclofop-methyl in wild oat and wheat. J. Agric. Food Chem. 27: 615-623.

Stephen, N.H., Cook, G.T., and Duncan, H.J. 1980. A possible mechanism of action of asulam involving folic acid biosynthesis. Ann. Appl. Biol. 96: 227-234.

Stern, H. 1966. The regulation of cell division. Ann. Rev. Plant Physiol. 17: 345-378.

Strang, R.H., and Rogers, R.L. 1971. A microautoradiographic study of ^{14}C-trifulralin absorption. Weed Sci. 19: 363-369.

Taylor, M.J., Ayres, P., and Turner, D.J. 1982. Effect of surfactants and oils on the phytotoxicity of difenzoquat to Avena fatua, barley and wheat. Ann. Appl. Biol. 100: 353-363.

Thiessen, E.P., Stephenson, G.R., and Anderson, G.W. 1980. Factors influencing 1,8-naphthalic anhydride activity as an antidote to barban in oats. Can. J. Plant Sci. 60: 1005-1013.

Todd, B.G., and Stobbe, E.H. 1977. Selectivity of dichlofop-methyl among wheat, wild oat (Avena fatua) and green foxtail (Setaria viridis). Weed Sci. 25: 382-385.

Veerasekaran, P., Kirkwood, R.C., and Parnell, E.W. 1981. Studies of the mechanism of action of asulam in plants. Part I: Antagonistic interaction of asulam and 4-aminobenzoic acid. Pestic. Sci. 12: 325-329.

Veerasekaran, P., Kirkwood, R.C., and Parnell, E.W. 1981. Studies of the mechanism of action of asulam in plants. Part II: Effect of asulam on the biosynthesis of folic acid. Pestic. Sci. 12: 330-338.

Venis, M.A. 1982. The rational design of the optically active wild oat herbicide L-flamprop-isopropyl. Pestic. Sci. 13: 309-317.

Walter, H., and Bischof, F. 1976. Uber die applikationsortabhängige Wirkung neuer Nachauflaufherbizide gegen Flughafer (Avena fatua L.). Z. Pflanzen-krankh. Pflanzenschutz 83: 338-351.

MODE OF ACTION OF AVENGE (DIFENZOQUAT)

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ABSTRACT

The actual site of action of difenzoquat has yet to be determined. However, the selective activity does appear to lie in differences at the site of activity.

Difenzoquat (1,2-dimethyl-2,5-diphenylpyrazolium methyl sulfate) is a water soluble herbicide for the selective control of wild oats (Avena spp.) in barley and tolerant wheat cultivars. Difenzoquat is applied postemergence to wild oats in the 3- to 5-leaf stage. There may be no visible effects of treatment on the wild oats until 10 to 14 days after application, except for a cessation of growth. This is followed by chlorosis of the tissue and death of the plant (Winfield and Caldicott, 1975). Sublethal doses of the herbicide to wild oats and sensitive wheat cultivars cause arrested growth, prolific tillering and main shoot death (Shafer, 1974). Tolerant crops treated with difenzoquat may show transient discoloration affecting 5 to 20% of the leaf surface. These symptoms disappear within 10 to 14 days and do not appear to adversely affect the subsequent growth of the crop or the yield (Winfield and Caldicott, 1975). Barley is extremely tolerant of difenzoquat while wheat cultivars vary in their tolerance, with some being very tolerant and others so adversely affected that they cannot be safely treated with the herbicide (Miller et al., 1978; Tottman et al., 1982).

The purpose of this paper is to describe the mode of action of difenzoquat. The mode of action of a herbicide includes the absorption and translocation characteristics of the compound as well as the inhibitory effects at the site of action. First to be discussed will be the absorption and translocation of the chemical and then what is known about its site of action will be reviewed.

ABSORPTION

Since difenzoquat is a postemergence herbicide, the primary site of application is the leaf tissue. Work by Sharma et al. (1976) showed that although roots of wild oats rapidly absorbed difenzoquat, upward translocation was limited and slow. They concluded that the herbicide was either absorbed tightly to the surface of the roots or was tightly bound to cellular components of the cortical parenchyma and did not enter the xylem until these sites were saturated. Consequently, difenzoquat has little or no activity when applied to the roots.

Difenzoquat is readily absorbed through foliage of wild oats, wheat and barley. Sharma *et al.* (1976) found that penetration continued over a 72-hour period. The presence of a non-ionic surfactant greatly increased the absorption of difenzoquat, up to 4-fold (Sharma *et al.*, 1976) (Table 1). The recommended level of surfactant for field applications is up to 0.5% in the spray volume. Merritt (1982) showed that increasing or decreasing the concentration of the surfactant 10-fold from the recommended level decreased the activity of difenzoquat on wild oats (Table 2). Merritt (1982) reported that increasing the concentration of surfactant to 5% caused an increase in the localized scorch at the site of application and this decreased the amount of herbicide translocated from the treated leaf.

Table 1 Effect of various concentrations of octoxynol surfactant on the penetration of ^{14}C-difenzoquat in wild oat

	Amount of the applied ^{14}C in leaves	
Octoxynol (%)	8 hr (%)	32 hr (%)
0.0	5.7	9.9
0.01	10.2	22.2
0.05	18.8	53.4
0.1	20.0	66.2
0.2	30.7	68.0
0.3	32.2	76.2
0.4	35.3	76.9
L.S.D. -5%	3.4	5.3

(Adapted from Sharma *et al.*, 1976).

Table 2 The effect of three doses of difenzoquat with three concentrations of Agral surfactant on the fresh weight of *A. fatua* (as a % of untreated plants). Growth stage, 13

Agral concentration	Dose (µg per plant)		
ml/litre	11.4	22.7	45.4
0.5	98	91	71
5.0	58	21	17
50.0	49	18	12
S.E. mean		6.6	
D.F.		63	

Values are means of eight replicates.

(Adapted from Merritt, 1982).

The concentration of difenzoquat per unit volume of spray solution and droplet size are also very important. Merritt (1982) and Taylor et al. (1982) found that droplets of 150 µ or less resulted in the maximum activity of difenzoquat applications through a controlled droplet application (CDA) of very low spray volumes of 5 to 40 L/ha, which increases the concentration of difenzoquat per droplet, also decreased activity. This decrease is correlated to increased scorching at the site of application resulting in reduced movement of the herbicide from the treated region (Merritt, 1982; Taylor et al., 1982). Taylor et al. (1982) found that the addition of a crop oil/surfactant additive to low spray volume applications of difenzoquat increased activity due to improved spreading and wetting properties of the spray which reduced the localized contact activity of the herbicide.

Aerial applications of difenzoquat in a spray volume of 10 to 20 L/ha have out-performed ground applications without increased scorching. This phenomenon is possibly due to the very small droplet size from aerial applications.

Table 3 Effect of temperature on the penetration of ^{14}C-difenzoquat in wild oat

	Amount of the applied ^{14}C in leaves		
Temperature (C)	2 hr (%)	4 hr (%)	8 hr (%)
10	1.3	2.3	4.5
20	4.2	10.5	18.3
30	6.5	15.8	26.7
L.S.D.-5%	0.7	1.2	2.8

(Adapted from Sharma et al., 1976).

Table 4 Effect of relative humidity on the penetration of ^{14}C-difenzoquat in wild oat

	Amount of the applied ^{14}C in leaves		
Treatment	2 hr (%)	4 hr (%)	8 hr (%)
Low humidity (30%)	4.2	10.5	18.3
High humidity (90%)	5.5	13.5	32.7
Low humidity (30%) plus re-wetting	5.3	12.0	24.7
L.S.D.-5%	0.8	1.6	3.1

(Adapted from Sharma et al., 1976).

Several researchers (Sharma *et al.*, 1976; Coupland *et al.*, 1978; Miller *et al.*, 1978) have demonstrated that high humidity and temperature increase the activity of difenzoquat, presumably due to increased penetration (Tables 3 and 4). Rainfall of 2 mm or more within 4 hours after application can reduce the activity of difenzoquat (O'Sullivan and Vanden Born, 1978; Caseley and Coupland, 1980; Miller *et al.*, 1978). Caseley and Coupland (1980) showed that 2 mm of simulated rainfall within 30 minutes after application removed 60% of the applied dose of difenzoquat from the leaves (Table 5). However, rainfall of 0.16 mm did not affect activity but redistributed the herbicide to the lower leaf/ligule area (Table 6). Work by Coupland *et al.*, (1978) showed difenzoquat worked best when applied to the youngest, fully-expanded leaves and when applied at the leaf base as opposed to the leaf tip (Table 7). Application of difenzoquat to the inner surface of the leaf sheath of wild oats resulted in the maximum absorption and translocation of the herbicide. The increased absorption was found in those parts of the leaf where the wax on the leaf surface was very thin with little structure (Caseley and Coupland, 1980).

Table 5 Retention of difenzoquat on foliage after 0, 0.5 and 2.0 mm of simulated rain

'Rain' (mm)	Difenzoquat retention (µg/g dry wt)		% Removed
0	228.9	(6.7)	
0.5	162.2	(8.3)	29.1
2.0	91.5	(7.2)	60.0

Values are means of 10 replicates, S.E. in parentheses.

(Adapted from Caseley and Coupland, 1980).

Table 6 Redistribution of difenzoquat on last fully-expanded leaf by 0.16 mm 'rain'

Section	Amount of difenzoquat recovered (µg) No 'rain'	'rain'	% reduction(-) or increase(+)
Apical 1/3rd of lamina	5.3	4.3	-20.8
Middle 1/3rd of lamina	7.7	7.4	-3.9
Basal 1/3rd of lamina	6.3	5.4	-14.3
Leaf base/ligule area	2.0	4.2*	+110.0
Rest of leaf sheath and stem	0.6	0.6	0
Total	21.9	21.9	

Values are means of four replicates.
*indicated significant difference from no rain treatment (S.E. = ± 0.446).

(Adapted from Caseley and Coupland, 1980).

Table 7 Effect of difenzoquat applied at three concentrations to three positions on leaf 2 of *Avena fatua* at growth stage 13

Position of treatment	Foliage fresh wt (as % control)		
	0.8 µg/µl	4 µg/µl	20 µg/µl
Control = 1.73g			
Treatments:			
Lamina apex	63.6	72.3	63.0
Lamina base	54.9	42.8	37.6
Between leaf sheath and 'stem'	40.5	25.4	11.6
L.S.D.-1% 13.8			

Volume applied at each position = 5 µl
Values are means of eight replicates. LSD at P=0.01.
(Adapted from Coupland *et al.*, 1978).

Absorption appears also to play a large role in the compatibility of difenzoquat with other postemergence herbicides. Difenzoquat can be tank-mixed with ester formulations of 2,4-DP, 2,4-D, MCPA or bromoxynil without loss in activity on wild oats. However, if difenzoquat is mixed with amine formulations of these broadleaf herbicides, wild oat activity may be decreased. Difenzoquat can also be mixed with barban, another wild oat herbicide, resulting in an additive effect (O'Sullivan, 1981). Sharma *et al.*, (1976) found that the ester formulations of the above mentioned broadleaf herbicides and barban increased the absorption of difenzoquat into wild oat leaves while an amine formulation had no effect on absorption (Table 8).

Table 8 Effect of various herbicides on the penetration of ^{14}C-difenzoquat in wild oat

Herbicide	Rate (kg/ha)	Amount of the applied ^{14}C in leaves 2 hr (%)	8 hr (%)
None	-	4.2	18.3
Bromoxynil + MCPA (1:1, w/w)	0.56	6.9	23.2
2,4-D amine	0.56	3.6	16.9
2,4-D ester	0.56	20.9	53.7
barban	0.14	15.9	40.4
L.S.D.-5%		2.3	2.5

(Adapted from Sharma *et al.*, 1976).

Difenzoquat is incompatible with propanil as shown by O'Sullivan (1981). Sharma and Vanden Born (1982) clearly showed that the antagonism between the two herbicides was due to a dramatic decrease in the absorption of difenzoquat when combined with propanil (Table 9).

Table 9 Uptake of ^{14}C-difenzoquat by wild oats at the three-leaf stage as influenced by propanil or propanil/MCPA, 24 h after application

Treatment	^{14}C in plants (% of total recovered)
Difenzoquat	18
Difenzoquat + propanil	4
Difenzoquat + propanil/MCPA	7
Difenzoquat + TRITON X-100	72
Difenzoquat + TRITON X-100 + propanil	12
Difenzoquat + TRITON X-100 + propanil/MCPA	15
LSD 5%	5
$S\bar{x}$	2

(Adapted from Sharma and Vanden Born, 1982).

In conclusion, the efficacy of difenzoquat depends on the amount of the herbicide that is absorbed by wild oats. Factors which affect absorptivity (i.e., surfactants, humidity, temperature, rainfall, other herbicides) will affect the activity of the herbicides.

TRANSLOCATION

Based on the symptomatology of difenzoquat (i.e., arrested growth, death of the main stem, prolific tillering) the primary site of action appears to be the meristematic tissue of wild oats. Since difenzoquat is applied to the foliage, it has to be translocated to the meristematic zone. Work by Friesen and Litwin (1975), Sharma *et al*. (1976) and Caseley and Coupland (1980) showed that difenzoquat moves acropetally in the leaf blade and only 1 to 2% of the applied dose is translocated to the rest of the plant. The pattern of translocation is similar in wild oats, barley, and wheat. Caseley and Coupland (1980) found that about 50% of difenzoquat applied to the inner surface of the leaf sheath was translocated to the rest of the plant. It is possible that only the herbicide which penetrates the leaf base/ligule area of a leaf results in the death of the weed.

SITE OF ACTION

The selectivity of difenzoquat cannot be accounted for by differences in the pattern of absorption and translocation in tolerant vs. susceptible species (Friesen and Litwin, 1975; Sharma et al., 1976). Sharma et al. (1976) also showed that difenzoquat is not rapidly metabolized in wild oats, barley, or wheat. Other factors must contribute to the selectivity of the herbicide possibility at the site of action.

Difenzoquat has two types of herbicidal activity, a contact activity which causes chlorosis and necrotic spots on the treated leaf and a systemic activity which kills the meristematic tissues. Contact activity is not selective. Pallett (1982) studied the contact activity of difenzoquat in two spring wheat cultivars and found that application of the herbicide increased the rate of electrolyte leakage, decreased chlorophyll content, and caused chloroplast abnormalities. Chow (1982) also found that difenzoquat decreased the chlorophyll content and photosynthesis in wild oats 6 days after application. Halling (1981) reported that difenzoquat could act as a weak autoxidizing electron acceptor of photosynthetic electron transport with a paraquat-type activity. Difenzoquat is closely related to the bipyridiliums and may be a weak paraquat-type herbicide. High concentrations in treated tissue could cause the contact activity of difenzoquat. Merritt (1982) and Taylor et al. (1982) found that application of large droplets containing high concentrations of the herbicide resulted in decreased herbicidal actfvity that was correlated with increased necrosis at the site of application. These observations are consistent with a paraquat-like activity. This contact activity is transitory and does not appear to play a large role in the selective phytotoxicity of difenzoquat.

The systemic activity of difenzoquat occurs at the meristematic zones of wild oats and involves an inhibition of cell division and elongation. Friesen and Litwin (1975) reported that application of difenzoquat close to the apical meristem of wild oats caused extensive chromosome abnormalities and cell necrosis. Pallett and Caseley (1980) compared the responses of a susceptible and tolerant cultivar of spring wheat to difenzoquat. DNA synthesis (measured by ^{14}C-thymidine incorporation) in the susceptible cultivar was inhibited by a lower concentration of the herbicide than in the tolerant cultivar. Uptake of ^{14}C-thymidine was also more inhibited in the susceptible cultivar. However, incorporation of ^{14}C-thymidine was inhibited within 15 minutes after exposure to 0.1 mM difenzoquat before uptake was inhibited. These results indicated that DNA synthesis may be a primary site of action of difenzoquat. Pallett and Caseley (1980) suggested that this differential inhibition of DNA synthesis and subsequent cell division could contribute to the different responses of the two cultivars to difenzoquat. The mechanism of inhibition of DNA synthesis by difenzoquat was not determined.

Cohen and Morrison (1982) looked at the effect of difenzoquat on potassium absorption in excised roots of susceptible wild oats and tolerant wheat and barley. They found that the chemical inhibited the uptake of potassium in all three species, but wild oats were more sensitive to low concentrations of the herbicide than the two tolerant crops. This inhibition could be detected within 10 minutes after application of the herbicide. The inhibition of potassium uptake was not due to increased passive permeability of the roots but appeared to be due to interference with the uptake processes themselves. This inhibition of ion uptake may be related to the inhibition of DNA synthesis observed by Pallett and Caseley (1980) since significant interrelationships can exist between the inhibitory effect of a herbicide on macromolecular synthesis and primary interferences with energy availability and solute transport.

REFERENCES

Caseley, J.C., and Coupland, D. 1980. Effect of simulated rain on retention, distribution, uptake, movement, and activity of difenzoquat applied to Avena fatua. Ann. Appl. Biol. 96: 111-118.

Chow, P.N.P. 1982. Wild oat (Avena fatua) herbicide studies: I. Physiological response of wild oat to five postemergence herbicides. Weed Sci. 30: 1-6.

Cohen, A.S., and Morrison, I.N. 1982. Differential inhibition of potassium ion absorption by difenzoquat in wild oats and cereals. Pest. Biochem. Physiol. 18: 174-179.

Coupland, D., Taylor, W.A.T., and Caseley, J.C. 1978. The effect of site of application on the performance of glyphosate on Agropyron repens, and barban, benzoylprop-ethyl and difenzoquat on Avena fatua. Weed Res. 18: 123-128.

Friesen, H.A., and Litwin, O.B. 1975. Selective control of wild oats in barley with AC 84 777. Can. J. Plant Sci. 55: 927-934.

Halling, B. 1981. Investigations on the mechanism of action of difenzoquat. Ph.D. Thesis. Univ. of Manitoba.

Merritt, C.R. 1982. The influence of form of deposit on the phytoxicity of difenzoquat applied as individual drops to Avena fatua. Ann. Appl. Biol. 101: 517-525.

Miller, S.D., Nalewaja, J.D., Pudelko, J., and Adamczewski, K.A. 1978. Difenzoquat for wild oat (Avena fatua) control. Weed Sci. 26: 571-576.

O'Sullivan, P.A. 1981. Control of wild oats, green foxtail and tartary buckwheat with mixtures of propanil or propanil/MCPA and postemergence wild oat herbicides. Can. J. Plant Sci. 61: 383-390.

O'Sullivan, P.A., and Vanden Born, W.H. 1978. Interaction between difenzoquat and other herbicides for wild oat and broadleaved weed control in barley. Weed Res. 18: 257-263.

O'Sullivan, P.A., and Vanden Born, W.H. 1980. The influence of immersion in water on the efficacy of postemergence wild oat herbicides. Can. J. Plant Sci. 60: 307-309.

Pallett, K.E. 1982. The contact activity of difenzoquat in two United Kingdom spring wheat cultivars. Weed Res. 22: 329-335.

Pallett, K.E., and Caseley, J.C. 1980. Differential inhibition of DNA synthesis in difenzoquat tolerant and susceptible United Kingdom spring wheat cultivars. Pest. Biochem. Physiol. 14: 144-152.

Shafer, N.E. 1974. Difenzoquat: a new postemergent wild oat herbicide for wheat and barley. 12th Br. Crop Prot. Conf. Weeds Proc. 2: 831-838.

Sharma, M.P., Vanden Born, W.H., Friesen, H.A., and McBeath, D.K. 1976. Penetration, translocation and metabolism of ^{14}C-difenzoquat in wild oat and barley. Weed Sci. 24: 379-384.

Sharma, M.P., and Vanden Born, W.H. 1982. Interaction between difenzoquat and propanil or propanil/MCPA combinations for wild oat and green foxtail control in barley. Can. J. Plant Sci. 62: 453-459.

Taylor, M.J., Ayres, P., and Turner, D.J. 1982. Effect of surfactants and oils on the phytotoxicity of difenzoquat to Avena fatua, barley and wheat. Ann. Appl. Biol. 100: 353-363.

Tottman, D.R., Lupton, F.G.H., Oliver, R.H., and Preston, S.R. 1982. Tolerance of several wild oat herbicides by range of winter wheat varieties. Ann. Appl. Biol. 100: 365-373.

Winfield, R.J., and Caldicott, J.J.B. 1975. Difenzoquat, 1,2-dimethyl-3,5-diphenyl-pyrazolium ion, a selective herbicide for the control of wild oats (Avena spp.) in wheat and barley. Pestic. Sci. 6: 297-303.

CARBYNE

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ABSTRACT

Barban is a herbicide that is quickly absorbed but demonstrates very little translocation. Barban is highly selective but what makes it so has not been attributed to any one factor. It interferes with cell division, inhibits protein and RNA synthesis and affects other biochemical processes, but a clear understanding of barban's mode of action has yet to be determined.

Carbyne was one of the first herbicides introduced to control wild oats. The Spencer Chemical Company was involved in the initial research and development of the product during the 1950s. Carbyne was registered in Canada in 1960, becoming a Velsicol product in 1980 with its acquisition from Gulf.

Carbyne is a carbamate herbicide. The active ingredient is 4-chloro-2-butynyl-m-chlorocarbanilate, or barban, as it is commonly referred to. It is highly selective controlling wild oats in a variety of crops. Application is postemergent to the crop and the wild oats must be in the 1 1/2 - 2 1/2 leaf stage for Carbyne to be effective.

Barban can be described as a mitotic poison in that it interferes with cell division. Barban-treated wild oats reveal large swollen cells containing numerous groups of chromosomes with no nuclear membrane or nucleoli present (Dubrovin, 1959). It is believed that the herbicide negatively affects microtubular formation, thus suppressing spindle formation. Subsequent chromosome separation and cell wall formation is therefore inhibited. The result is that the wild oat plant ceases to grow, due to the interference of cell division within the apical meristem.

ABSORPTION AND TRANSLOCATION

Foy (1961) reported that barban was absorbed and translocated in small amounts when applied to the upper surface of the first leaf of wild oats. The greatest movement was towards the leaf tips along the transpiration stream. It was also observed that applying barban at the axil of the first leaf led to the greater amounts of the herbicide being absorbed and translocated.

Experiments on barban selectivity carried out by Neidermyer and Malewaja (1974) confirmed Foy's results. Treating wild oats with barban at the coleoptilar node, as well as above and below this point, they measured the growth of the second leaf. Data indicated that wild oat growth was reduced when barban was applied to sites below the coleoptilar node. The conclusion was that barban was not translocated downward readily but was translocated upward towards the shoot apex.

A study of the interaction of barban and growth regulator herbicides by Chow and Taylor (1983) showed that the greatest degree of translocation of barban was upwards toward the leaf tips. They also determined that approximately 95% of the applied barban remained in the treated area. This demonstrated again that barban is not translocated.

Barban absorption is one area researchers believe contributes to its selectivity among susceptible and tolerant species. Foy (1961) reported no differences on barban absorption among barley, oats and wild oats, but contrasting data has been reported.

Kobayashi and Ishizuka (1974) found barban was absorbed at a much higher rate by oats than wheat. Since translocation or molecular fate of barban was similar between the two species, the authors concluded differential absorption was one of the main factors in determining selectivity to barban.

Shimabukuro _et al_. (1976) investigated the role of the coleoptile on barban sensitivity between wild oats and wheat. They suggested that differential absorption by the coleoptile of wild oat and wheat contributed to barban's selectivity, but it was not the only reason. It was also discovered that the coleoptile of wheat metabolized barban to a much greater extent than the coleoptile of wild oats. The stem of wild oats, therefore, had accumulated a higher free barban concentration. The presence of differential metabolism may also contribute to barban's selectivity.

BIOCHEMICAL RESPONSES

Mann _et al_. (1965) reported barban inhibited methionine incorporation into a polymer, which may have been responsible for the mitotic abnormalities associated with barban-treated wild oats. Barban has also blocked gibberellin-induced amylase synthesis, as well as reduced the rate of amino acid incorporation (Mann _et al_., 1967). Kobayashi and Ishizuka (1974) indicated amino acid incorporation into protein was inhibited in oats but not in wheat.

Studies by Chow (1982) revealed that barban inhibited photosynthesis but did not affect the chlorophyll content of wild oats. It had very little or no effect upon translocation of photosynthate from the leaves to the roots. Barban also reduced the content of the amino acids serine and threonine. Total protein in wild oat decreased due to the inhibition of RNA synthesis.

MOLECULAR FATE OF BARBAN

Barban is degraded quite rapidly in most plant species. Within 2 weeks of application up to 99% of the barban may be lost (Riden and Hopkins, 1961). Riden and Hopkins (1962) reported barban was converted to a water soluble, 3-chloroaniline-containing substance which they designated compound X. Maximum formation of X occurred after the second or third day of treatment and could account for up to 60% of the applied barban. After this point, it declined slowly to zero as the crop matured. Analysis of leaf sections found barban and compound X at the initial site of application implying little or no translocation. They determined that barban's toxic effects were not dependent upon compound X as all carbamates studied, active or inactive, produced a similar substance.

Jacobsohn and Andersen (1972) tested two wild oat biotypes and two barley varieties for differential response to barban. A greater accumulation of compound X was found in the susceptible biotype or variety. As stated previously, differential response seemed to depend upon the resistant species' ability to degrade barban more readily than susceptible species.

REFERENCES

Chow, P.N.P. 1982. Wild oat (Avena fatua) herbicide studies: 1. Physiological response of wild oat to five postemergence herbicides. Weed Sci. 30: 1-6.

Chow, P.N.P., and Taylor, H.F. 1983. Wild oat herbicide studies. 3. Physiological and biochemical bases for interaction of barban and growth regulator herbicides in wild oat. J. Agr. Food Chem. 31: 575-578.

Dubrovin, K.P. 1959. Cyto-histological responses of wheat and wild oats to Carbyne. Proc. N. Central Weed Control Conf. 16:15.

Foy, C.L. 1961. Uptake of radioactive 4-chloro-2-butynyl N-(3-chlorophenyl) carbamate (barban) and translocation ^{14}C in Hordeum vulgar and Avena spp. Res. Prog. Rep. West. Weed Contr. Conf.: 96-97.

Jacobsohn, R., and Andersen, R.N. 1972. Intraspecific differential response of wild oat and barley to barban. Weed Sci. 20: 74-80.

Kobayashi, K., and Ishizuka, K. 1974. Selective herbicidal action of barban on oat and wheat plants. Weed Sci. 22: 131-135.

Mann, J.D., Jordan, L.S., and Day, B.E. 1965. The effects of carbamate herbicides on polymer synthesis. Weeds 13: 63-66.

Mann, J.D., Cota-Robles, E., Yung, K.H., Pu, M., and Haid, H. 1967. Phenylurethane herbicides: Inhibitors of changes in metabolic state. 1. Botanical aspects Biochem. Biophys. Acta. 138: 133-139.

Neidermyer, R.W., and Nalewaja, J.D. 1974. Barban selectivity for wild oat in wheat. Weed Sci. 22: 476-480.

Riden, J.R., and Hopkins, T.R. 1961. Decline and residue studies on 4-chloro-2-butynyl N-(3-chlorophenyl) carbamate. J. Agr. Food Chem. 9: 47-49.

Riden, J.R., and Hopkins, T.R. 1962. Formation of a water soluble, 3-chloroaniline-containing substance in barban-treated plants. J. Agr. Food Chem. 10: 455-458.

Shimabukuro, R.H., Walsh, W.C., and Hoerauf, R.A., 1979. The role of coleoptile on barban sensitivity between wild oat and wheat. Pestic. Biochem. Physiol. 6: 115-125.

MODE OF ACTION OF THE WILD OAT HERBICIDE DICLOFOP-METHYL

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ABSTRACT

The present knowledge of the mode of action of the herbicide 2-(4-(2', 4'-dichlorophenoxy)-phenoxy)-methylpropanoate (diclofop-methyl) is reviewed. This herbicide selectively controls wild oat and other grass weeds in wheat, barley and dicotyledonous crop species.

After postemergence application of diclofop-methyl to wild oat and other susceptible grass weeds, leaf growth is rapidly arrested accompanied by the appearance of leaf chlorosis. Subsequently, the meristematic areas at the shoot base turn necrotic. Diclofop-methyl is also a stong inhibitor of root growth.

The first step of diclofop-methyl degradation in plants is rapid hydrolysis to 2-(4-(2', 4'-dichlorophenoxy)-phenoxy)-propionic acid (termed "diclofop" or "diclofop acid") which is also phytotoxic. It is subsequently inactivated by hydroxylation in the 2,4-dichlorophenyl ring and by conjugate formation. Ring hydroxylation, which is regarded as a true detoxification mechanism, dominates in tolerant wheat, whereas formation of ester conjugates of diclofop acid (assumed to be reversible) dominates in susceptible wild oat. The different pattern of degradation in these two species is likely to be the basis for differential susceptibility. The physiological basis for the high diclofop-methyl tolerance of dicotyledonous species is not yet clear.

Diclofop-methyl is most effective at the optimum temperature for growth of the target grass weeds. Its rainfastness is high. Moisture stress reduces herbicidal effectiveness.

The auxin type herbicides 2,4-D and 2,3,6-TBA increase the rate of diclofop acid conjugation reactions in oat, which may explain why these herbicides reduce the effectiveness of diclofop-methyl.

Diclofop-methyl does not directly interfere with photosynthesis and respiratory O_2-uptake of susceptible

> grass species. It has little or no effect on incorporation of radiolabelled precursors into nucleic acids and proteins. Incorporation of radiolabelled acetate into lipids of root tips and young leaves is strongly inhibited. Root growth inhibition and inhibition of lipid biosynthesis appear well correlated in dosage/effect studies. Diclofop-methyl interferes with *de novo* synthesis of fatty acids in grass species. In contrast to *Zea mays*, which was employed in biosynthesis studies as a representative of highly susceptible grass species, even high diclofop-methyl concentrations did not affect lipid biosynthesis in the highly tolerant *Phaseolus vulgaris*.

The herbicide 2-(4-(2', 4'-dichlorophenoxy)-phenoxy)-methylpropanoate (common name: diclofop-methyl)* was discovered by Hoechst AG in 1971. It selectively controls a broad spectrum of annual grass weeds in wheat, barley and dicotyledonous crops. The main target weeds of this herbicide are wild oat species (*Avena* spp.). Other grass weeds highly susceptible to diclofop-methyl are wild millets (e.g., *Echinochloa* spp., *Setaria* spp.), rye grass (*Lolium* spp.) and volunteer corn (*Zea mays*). Diclofop-methyl is predominantly applied postemergence in the 2- to 4-leaf stage of the weeds, but has also some preemergence potential.

This review will concentrate on research work dealing with the effects of diclofop-methyl on wild oats and the physiological basis of selective action. Results obtained with other susceptible grass species will be included if they contribute to the understanding of the mode of action of this herbicide.

MORPHOLOGICAL SYMPTOMS

About three days after postemergence application, the leaves of susceptible grass species become chlorotic and the growth of new leaves is arrested. Usually, between 7 to 10 days after spraying, the chlorotic areas become necrotic, as do the meristematic zones of the shoot axis. The destruction of the intercalary meristems and the apical meristem of the shoot is essential for a complete kill of the plant (Hoerauf and Shimabukuro, 1979; Köcher and Lötzsch, 1975, 1981; Walter, 1977; Walter and Bischof, 1976).

Ultrastructural studies on wild oat leaf tissue showed that the chloroplasts are the cell organelles most affected by diclofop-methyl. The results were indicative of breakdown of membrane systems in chloroplasts already existing at the time of herbicide treatment, or of abnormal membrane formation in chloroplasts developing after herbicide application. In an advanced stage of cellular damage the plasmalemma was detached from the cell walls, the tonoplast was injured, and numerous vesicles appeared in the vacuole (Brezeanu *et al*., 1976).

* Registered trade marks of Hoechst AG: Hoe-Grass, Hoelon, Illoxan

The growth of roots of susceptible grass species is strongly inhibited and necrosis starts from the meristematic zone at the root tip (Hoppe, 1980b, Köcher and Lötzsch, 1975). Growth of the primary root of seedlings of oat (Avena sativa) and wild oat (Avena fatua) was 50% inhibited in aqueous solutions of diclofop-methyl and its free acid (diclofop acid) at concentrations as low as 10^{-7} M (Köcher and Lötzsch, 1975). In another study, reduction in the length of the primary root of wild oat seedlings was even reported at 10^{-8} M diclofop-methyl. Number and length of adventitious roots were not affected at this concentration. At 10^{-7} M diclofop-methyl stimulated the number of adventitious roots emerging from the crown, but inhibited their elongation. Both adventitious root emergence and elongation were inhibited at 10^{-6} M diclofop-methyl (Donald et al., 1982). In comparison to aqueous herbicide solutions, inhibition of oat seedling root growth was not as strong--though still considerable--when the seedlings were exposed to soil treated with herbicide. In bioassay studies on a clay soil under laboratory conditions it was found that the length of the primary root of oat seedlings still showed a clear and reproducible response to diclofop acid residues at a concentration of 0.2 ppm (Hsiao and Smith, 1983). In wild oat plants with the roots immersed in nutrient solution with 3 x 10^{-7} M diclofop-methyl, the anatomy of the root tip was strongly affected by the herbicide. Most striking was the strong damage to the tissue in the developing central cylinder close to the root apex, which was already apparent 1 day after treatment. Damage to the cortical and epidermal tissue of the root was not severe until 4 to 7 days after treatment (Morrison et al., 1981).

UPTAKE AND TRANSLOCATION

Time course studies showed that uptake of diclofop-methyl after foliar application extends over a period of 4 days or more, the rate of uptake being highest on the day of treatment. Todd and Stobbe (1977) found about 70% uptake in wild oat (Avena fatua) and 90% in wheat (Triticum aestivum) 4 days after foliar application. Donald and Shimabukuro (1980), found after the same period about 57% absorption in wild oat and 50% in wheat. In this study the time course of foliar uptake was similar for the 2 species, whereas Todd and Stobbe (1977) found even a higher initial rate of uptake for wheat than for wild oat. These results suggest that the selective action of diclofop-methyl cannot be explained by differential rates of uptake by the tolerant and the susceptible species. The same conclusions were drawn by Boldt and Putnam (1980) from their comparative uptake studies with dicotyledonous species (all tolerant) and various grass species tolerant and susceptible to diclofop-methyl. Also differential retention of spray solution did not appear to be the mechanism of selectivity (Boldt and Putnam, 1980).

After foliar application of ^{14}C-labelled diclofop-methyl, translocation rates of radioactive material within the treated leaf were low, both in acropetal and basipetal direction. Three days after foliar application, total translocation in wheat amounted to 1.7%, in wild oat to 0.9% and in green foxtail (Setaria viridis) to 0.8% of the applied quantity of herbicide. The differences in susceptibility of these species to diclofop-methyl could not be explained by different translocation rates of radioactive label (Todd, 1979), neither did differential translocation appear to be a factor responsible for the high tolerance of dicotyledonous species as compared to the monocotyledonous target species of this herbicide (Boldt and Putnam, 1980). Autoradiographs of leaves from grass species and broad-leaved species treated with radiolabelled diclofop-methyl showed that the radioactive material translocated above and below the site of application was mainly located within the conducting tissues and decreased with increasing distance from the site of application (Köcher and Lötzsch, 1975). Selective placement of diclofop-methyl to different areas of the leaves of wild oat plants confirmed that the closer the site of application was to the base of the shoot, the higher was the concentration of the herbicide in the meristematic areas at the shoot base, as one would have expected. This was correlated with increased damage to the shoot meristems and to the plant in general (Walter and Bishof, 1976; Walter et al., 1980). Thus these wild oat studies and similar foliar placement experiments with corn (Köcher and Lötzsch, 1981), confirmed that diclofop-methyl does not only have a local action, but also a systemic action on the meristematic areas at the shoot base. Since the effectiveness of this herbicide drastically increases with decreasing distance between the site of application on the leaf and the meristematic tissues at the shoot base, in agricultural practice, spraying conditions should be chosen which ensure good deposition of diclofop-methyl at the base of the target plant species.

The roots of wild oat and wheat plants exposed to diclofop-methyl solutions absorbed the herbicide along the entire root length. However, in both species, absorption was greatest in the apical region of the roots. Less than 5% of the absorbed diclofop-methyl was translocated within the roots (Jacobson and Shimabukuro, 1982).

Placement experiments with plants growing in soil have shown that action via the soil can contribute to a limited extent to the overall action of diclofop-methyl applied postemergence (Bieringer, 1981; West et al., 1980). The leaching of this herbicide in soil is relatively low (Mulder and Nalewaja, 1979; Wu and Santelmann, 1976). Thus, it is obvious that low rainfall, especially in conjunction with high adsorptive properties of the soil, will adversely affect the soil action of this compound. For these reasons preemergence applications of diclofop-methyl at the usual postemergence rate give less consistent results than postemergence applications though the compound is a strong inhibitor of germinating grass weed seedlings. Particularly, wild oats can germinate from greater soil depths, and so may be less exposed to herbicide than shallow germinating grass weed seedlings. Higher dosages may

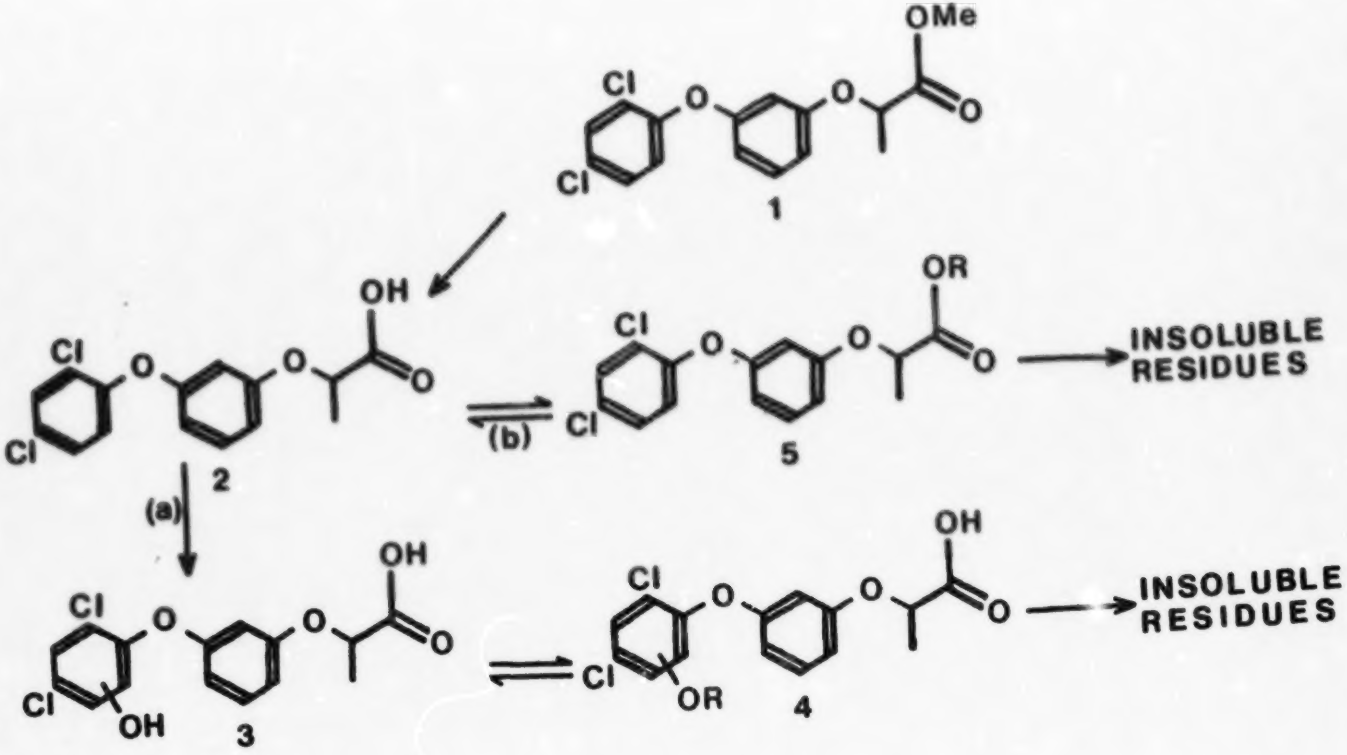
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Fig. 1 Proposed metabolic pathway for diclofop-methyl (1) to diclofop acid (2) and hydroxylated and conjugated compounds (3, 4 and 5) in wheat (pathway a) and wild oat plants (pathway b). (From Shimabukuro et al., 1978).

overcome the problems in preemergence application, but then treatment costs per acre are the limiting factor. Nevertheless, some preemergence applications became established, e.g., Bromus tectorum control in the northern United States (Seder and Fay, 1981) or rye grass control in other countries, due to the high susceptibility of these target weeds to diclofop-methyl.

DEGRADATION IN PLANTS

The first step of diclofop-methyl degradation in plants is rapid hydrolysis to 2-(4-(2',4'-dichlorophenoxy)-phenoxy)-propionic acid (termed "diclofop" or "diclofop acid"). This product is then hydroxylated to form 2-(4-(2',4-dichloro-5'-hydroxyphenoxy)-phenoxy)-propionic acid or the 3'- and 6'-isomers with respect to the position of the hydroxy group. The diclofop acid as well as the ring-hydroxylated metabolites can conjugate with plant constituents (Gorbach et al., 1977; Shimabukuro et al., 1979). Wild oat predominately conjugates diclofop acid to an ester conjugate. Wheat, in contrast, mainly hydroxylates the 2,4-dichlorophenyl ring, being followed by formation of phenolic conjugates (see Fig. 1).

The follow-up studies of diclofop-methyl metabolism in cell suspension cultures of Avena fatua and Triticum monococcum showed the same pattern of degradation as previously found in intact plants of Avena fatua and Triticum aestivum, respectively (Dusky et al., 1980, 1982). Diclofop-methyl and diclofop acid are phytotoxic. The aryl hydroxylation of diclofop acid, which is probably catalyzed by a microsomal mixed function oxidase, detoxifies the molecule. The subsequent conjugation of the hydroxylated acid, resulting in phenolic conjugates, is not expected to have any further effect on physiological activity. In contrast, the formation of ester conjugates of diclofop acid, which dominates in oat species, is not considered to be a true detoxification mechanism. It is assumed that the physiological inactive ester conjugate may be hydrolyzed in vivo to regenerate the phytotoxic diclofop acid, analogous to the ester conjugation and hydrolysis of IAA or chloramben. The available results of comparative metabolism studies on whole plants, coleoptiles, and cell cultures of wheat and oat species suggest that the key factor in selectivity is the hydroxylation of the diclofop acid in tolerant wheat versus the predominant formation of ester conjugates from diclofop acid in susceptible oat species (Gorecka et al., 1981).

Comparative studies of diclofop-methyl degradation in tolerant bushbeans representative of dicotyledonous species and susceptible corn did not indicate a relation between pattern of degradation and herbicide susceptibility of these two species (Zacher and Hoppe, 1981).

INFLUENCE OF ENVIRONMENTAL FACTORS ON HERBICIDE ACTION

Growth chamber experiments with different temperature regimes

(18°/10°C, 25°/17°C, 32°/24°C day/night) showed that, in general, diclofop-methyl was most effective at temperatures best suited for vigorous growth. Setaria viridis and Eleusine indica, for example, which grew better at 32°/24°C than at lower temperatures, was most effectively controlled at 32°/24°C. In contrast, wild oat, which produced less dry matter at 32°/24°C than at the lower temperatures, was controlled best at the lower temperature regimes (Donn and Bieringer, 1980).

The rainfastness of diclofop-methyl is high. When artificial rain (15 mm) was given 0.5 h after spraying wild oat with diclofop-methyl EC 36, wild oat control was reduced, though not significantly. When the rain was given 1.5 h after herbicide application, control was almost the same as without rain. Rain after 3, 6 or 24 h resulted in even better control of wild oat compared to the plants which did not receive rain (Bieringer, 1981).

Moisture stress reduced the postemergence effectiveness of diclofop-methyl on wild oat and other grass weeds. When contact of the herbicide spray with the soil was prevented by covering the soil surface with adsorbant material prior to herbicide application, the herbicide effectiveness on moisture-stressed plants was as much reduced as without prevention of soil contact. Changes in root uptake due to reduced soil moisture content were therefore not considered to be the reason for the altered activity of diclofop-methyl in relation to soil moisture (Dortenzio and Norris, 1980).

Retention of diclofop-methyl spray solution per gram leaf tissue by plants under moisture stress was somewhat lower than by unstressed plants. Penetration and metabolism of foliar-applied ^{14}C-labelled diclofop-methyl in wild oat was not significantly influenced by soil moisture status, but there was some reduction of basipetal translocation of radioactive material to the shoot apex and tillers of plants kept under moisture stress (Akey and Morrison, 1983). This may partially explain the reduced effectiveness of diclofop-methyl. But it is likely that, in addition, interference of moisture stress with physiological processes in the meristematic tissues of the shoot will influence the effectiveness of diclofop-methyl at its biochemical site(s) of action.

INTERACTIONS BETWEEN DICLOFOP-METHYL AND AUXIN-TYPE HERBICIDES

Early in the development of diclofop-methyl it became apparent that auxin-type herbicides, for example 2,4-D, MCPA, dicamba, reduced the effectiveness of wild oat control, when they were applied in tank-mix with diclofop-methyl. This antagonism could be avoided by sequential application. MCPA, for example, did not reduce wild oat control when applied either 2 days before or 1 day after diclofop-methyl (Olson and Nalewaja, 1981; O'Sullivan and Vanden Born, 1976).

Studies of Todd and Stobbe (1977, 1980) gave no evidence for a physical or chemical interaction of 2,4-D amine and diclofop-methyl in the spray solution, nor was foliar retention of diclofop-methyl and penetration into the target weeds affected by the addition of 2,4-D amine. Translocation of radioactive material from the treatment zone on the second leaf of the wild oat to the tip of the treated leaf was increased when ^{14}C-labelled diclofop-methyl was applied in mixture with 2,4-D amine, whereas basipetal translocation to the shoot base and to the roots was decreased. Thin layer chromatography of the basipetally translocated radioactive material suggested that the antagonistic effect of 2,4-D amine on diclofop-methyl toxicity in wild oat was due to a reduced level of the phytotoxic diclofop acid at its site of action in the meristematic areas of the shoot base (Todd and Stobbe, 1980). Hall et al. (1982) found no effect of 2,4-D on translocation of diclofop-methyl in oat. They applied much lower herbicide concentrations than other investigators and concluded that at high concentrations 2,4-D may have caused cell damage at the site of application, thus affecting transport processes (Hall et al., 1982). Qureshi and Vanden Born (1979) studied the effect of MCPA on foliar uptake and subsequent metabolism of ^{14}C-labelled diclofop-methyl in wild oat. MCPA reduced foliar uptake of diclofop-methyl. Its rate of hydrolysis to diclofop acid was reduced, and at the same time formation of diclofop acid conjugates was accelerated. It was concluded that the combined action of these effects may explain the reduced effectiveness of diclofop-methyl when applied in mixture with MCPA (Qureshi and Vanden Born 1979). No influence of MCPA on the foliar uptake of ^{14}C-labelled diclofop-methyl in wild oat was found by Olson and Nalewaja (1982), but basipetal translocation of radioactive material was reduced.

It was also investigated whether diclofop-methyl and auxin-type herbicides may interact at the biochemical site of auxin. Shimabukuro et al. (1978, 1982) showed that diclofop-methyl and, to a less pronounced degree, diclofop acid, inhibited the IAA-stimulated elongation of oat coleoptiles. This inhibition could partially be overcome by an increase in IAA-concentration or by the addition of the auxin-type herbicide dicamba. Diclofop-methyl antagonized the IAA-induced hydrogen extrusion of (peeled) wild oat coleoptiles, suggesting that it may inhibit auxin-mediated cell responses by an action at specific membrane sites.

Olson et al. (1981) found no influence of IAA concentration on the concentration of diclofop-methyl required to give 50% inhibition of oat coleoptile growth, neither could they overcome oat coleoptile growth inhibition from diclofop-methyl or its free acid by the addition of MCPA. They concluded that diclofop-methyl and its free acid are not antiauxins, and that their site of action on plant growth and the site of MCPA antagonism of diclofop phytotoxicity appear to be different.

The results of Taylor et al. (1983) also point into this direction. In their experiments with oat plants 2,4-D antagonized diclofop-methyl, as was expected. But, surprisingly, antagonism was also exerted by the isomer 3,5-D (3,5-dichloro-phenoxyacetic acid), though this compound has no auxin activity. Among the substituted benzoic acids not only the auxin 2,3,6-trichlorobenzoic acid (2,3,6-TBA) was severely antagonistic, but also 2,3,5-triiodobenzoic acid (2,3,5-TIBA), which is inactive as an auxin. It was interesting that picloram, though it is a strong auxin-type herbicide, was only very slightly antagonistic. These results mean that antagonism with diclofop-methyl is related to certain chemical structures, but is not correlated with auxin activity. The antagonism does not appear to occur at the biochemical site of auxin action. The same investigators showed that the antagonism was not the consequence of physical or chemical changes in the tank-mix, but that it occurred within the plant. The ester hydrolysis of ^{14}C-labelled diclofop-methyl in oat was in all treatments complete within about an hour, but after longer incubation periods tissue from plants treated with diclofop-methyl alone had a higher residual content of diclofop acid, and correspondingly less conjugates than tissue from oat plants which had been treated in addition with various antagonists (Taylor and Loader, 1982; Taylor et al., 1983). Therefore, evidence is strong that the antagonism by substituted phenoxyalkanoic acids and benzoic acids is not due to an auxin-antiauxin interaction, but based on increased metabolism of diclofop acid to physiologically inactive metabolites. The results of several authors, who found reduced translocation of diclofop-methyl in the presence of antagonists, may not be unrelated, since conjugation may entail reduced mobility in the plant.

PHYSIOLOGICAL AND BIOCHEMICAL EFFECTS

Photosynthesis and respiration do not appear to be primary sites of action of diclofop-methyl. The reduction of photosynthetic CO_2-fixation, which is apparent several days after foliar application of diclofop-methyl to sensitive grass species, is a secondary effect due to damage of the chloroplast membranes and an associated reduction of chlorophyll content (Brezeanu et al., 1976; Chow and LaBerge, 1978; Chow, 1982; Köcher and Lötzsch, 1975). The O_2-uptake of isolated oat and wheat mitochondria was reduced only when the herbicide concentration was very high (0.5 mM), diclofop acid being more effective than diclofop-methyl. The results were similar for both plant species. Since diclofop-methyl and diclofop acid strongly inhibit growth processes already at much lower concentrations, the respiratory electron transport chain is unlikely to play a role in the action of this herbicide in vivo (Cohen and Morrison, 1981).

When applied to the foliage of susceptible grass species, diclofop-methyl reduced assimilate transport to the roots and caused an increase in soluble sugars in the shoot (Chow and LaBerge, 1978; Köcher and Lötzsch, 1975). The increase in soluble sugars in the shoot may not only be due to reduced transport to the root. It may be, at least in part, a consequence of the fact that the photosynthesis of treated plants continues for several days, while less photosynthates are needed for biosynthetic processes due to rapid growth inhibition.

Hoppe and Zacher (1982) chose corn seedlings as a sensitive model system to compare dose/response relations for the effects on root growth and on biochemical processes. A concentration of 5 x 10^{-6} M completely inhibited growth of the primary root of corn seedlings after 12 h of incubation, and 5 x 10^{-7} M still resulted in partial inhibition. In contrast, root growth of the tolerant bushbean (Phaseolus vulgaris) even continued at concentrations above 10^{-4} M (Hoppe, 1980b).

The influence of diclofop-methyl treatment over a period of 24 h on biosynthetic processes in corn root tips was studied by feeding ^{14}C-adenine, ^{14}C-leucine and ^{14}C-acetate. The herbicide had no effect on the incorporation of ^{14}C-leucine into proteins. There was only a weak effect on the incorporation of ^{14}C-adenine into nucleic acids, which was due to a slightly reduced uptake of the precursor. In contrast, incorporation of ^{14}C-acetate by the root tips was inhibited to a much lower degree. Diclofop-methyl caused a reduction of ^{14}C-activity in the lipids and an accumulation in water soluble compounds. Herbicide concentrations of 5 x 10^{-6} M and higher gave strong inhibition, and 5 x 10^{-7} M moderate inhibition of ^{14}C-acetate incorporation. This correlated well with the degree of root growth inhibition at these concentrations (Hoppe, 1980b, 1981a, 1981b).

The results of the ^{14}C-acetate incorporation study agree with the finding that the content of phospholipids was reduced in corn root tips after diclofop-methyl treatment (Hoppe, 1980a). Detailed studies showed that incorporation of ^{14}C-acetate into acyl lipids was inhibited already 12 h after treatment with diclofop-methyl whereas incorporation of ^{14}C-acetate of ^{14}C-mevalonate into sterols was reduced only after a 24 h pretreatment period. This delayed influence on sterol biosynthesis suggests a secondary effect on this metabolic pathway. If root tips were incubated in ^{14}C-glucose or ^{14}C-amlonic acid solutions, the label in the acyl lipids was reduced to the same degree as after incubation on ^{14}C-acetate. This indicates that acetyl thiokinase or formation of malonyl-CoA were not sites of action of diclofop-methyl. Also the incorporation of ^{32}P into phospholipids or the ^{14}C-oleic acid into acyl lipids was not inhibited by diclofop-methyl. The results suggested that this herbicide interferes with the de novo synthesis of fatty acids and that the site of inhibition is located before oleic acid. These conclusions were further supported by the finding that the inhibitory action of diclofop-methyl on corn root growth could at least partially be reversed by the addition of oleic or linoleic acid. It was concluded that via inhibition of lipid biosynthesis diclofop-methyl affects composition and function of plant membranes (Hoppe and Zacher, 1982).

The results on lipid biosynthesis which were first obtained on corn root tips, were later confirmed in studies with corn leaf tissue (Hoppe, 1981a). With leaf discs prepared from the youngest still developing leaves and floated in buffered diclofop-methyl solutions, it was shown that 5 x 10^{-6} M diclofop-methyl reduced the ^{14}C-acetate incorporation into lipids by more than 70%. In leaf discs of bushbean, a species highly tolerant to diclofop-methyl, even 5 x 10^{-5} M of the herbicide did not interfere with ^{14}C-acetate incorporation into lipids (Zacher and Hoppe, 1981). Since the pattern of uptake and degradation of diclofop-methyl in these two species could not explain the differential herbicide sensitivity, it appears that differences exist between the two species at the primary biochemical site of action of this herbicide. At present we cannot say whether diclofop-methyl directly interferes with fatty acid biosynthesis of grass species. It is as well possible that it affects lipid biosynthesis indirectly by interference with a cellular regulatory system.

REFERENCES

Akey, W.C., and Morrison, I.N. 1983. Effect of moisture stress on wild oat (Avena fatua) response to diclofop. Weed Sci. 31: 247-253.

Bieringer, H. 1981. Untersuchungen zum Einfluß von Bodenfeuchtigkeit and Niederschlägen auf die Wirksamkeit des Gräserherbizids Illoxan (Diclofop-methyl) im Nachauflaufverfahren. Z. Pflanzenkrankh. Pflanzenschutz, Sonderheft IX: 399-405.

Boldt, P.F., and Putnam, A.A. 1980. Selectivity mechanisms for foliar applications of diclofop methyl. I. Retention, absorption, translocation and volatility. Weed Sci. 28: 474-477.

Brezeanu, A.G., Davis, D.G., and Shimabukuro, R.H. 1976. Ultrastructural effects and translocation of methyl-2-(4-(2,4-dichlorophenoxy)-phenoxy)propanoate in wheat (Triticum aestivum) and wild oat (Avena fatua). Can J. Bot. 54: 2038-2048.

Chow, P.N.P., and La Berge, D.E. 1978. Wild oat herbicide studies. 2. Physiological and chemical changes in barley and wild oat treated with diclofop-methyl herbicide in relation to plant tolerance. J. Agric. Food Chem. 26: 1134-1137.

Chow, P.N.P. 1982. Wild oat (Avena fatua) herbicide studies: 1. Physiological response of wild oat to five post-emergence herbicides. Weed Sci. 30: 1-6.

Cohen, A.S., and Morrison, I.N. 1981. In vitro sensitivity of wheat and oat mitochondria to the selective herbicide, diclofop-methyl. Pest. Biochem. Physiol. 16: 110-119.

Donald, W.W., Parke, R.V., and Shimabukuro, R.H. 1982. The effect of diclofop-methyl on root growth of wild oat. Physiol. Plant. 54: 467-474.

Donald, W.W., and Shimabukuro, R.H. 1980. Selectivity of diclofop-methyl between wheat and wild oat: growth and herbicide metabolism. Physiol. Plant 49: 459-464.

Donn, G., and Bieringer, H. 1980. The influence of temperature on the herbicidal activity of diclofop-methyl against different weed grass species. Brit. Crop Prot. Conf. - Weeds Proc.: 283-288.

Dortenzio, W.A., and Norris, R.R. 1980. The influence of soil moisture on the foliar activity of diclofop. Weed Sci. 28: 534-539.

Dusky, J.A., Davis, D.G., and Shimabukuro, R.H. 1980. Metabolism of diclofop-methyl (methyl-2-[4-(2'4'-dichlorophenoxy)phenoxy] propanoate) in cell suspensions of diploid wheat (*Triticum monococcum*). Physiol. Plant. 49: 151-156.

Dusky, J.A., Davis, D.G., and Shimabukuro, R.H. 1982. Metabolism of diclofop-methyl in cell cultures of *Avena sativa* and *Avena fatua*. Physiol. Plant. 54: 490-494.

Gorbach, S.G., Kuenzler, K., and Asshauer, J. 1977. On the metabolism of HOE 23408 0 H in wheat. J. Agric. Food. Chem. 25: 507-511.

Gorecka, K., Shimabukuro, R.H., and Walsh, W.C. 1981. Aryl hydroxylation: A selective mechanism for the herbicides, diclofop-methyl and diclofop-isobutyl, in gramineous species. Physiol. Plant. 53: 55-63.

Hall, C., Edgington, L.V., and Switzer, C.M. 1982. Translocation of different 2,4-D, bentazon, diclofop, or diclofop-methyl combinations in oat (*Avena sativa*) and soybean (*Glycine max*). Weed Sci. 30: 676-682.

Hoerauf, R.A., and Shimabukuro, R.H. 1979. The response of resistant and susceptible plants to diclofop-methyl. Weed Res. 19: 293-299.

Hoppe, H.H. 1980a. Veränderungen der Membranpermeabilität, des Kohlenhydratgehaltes, des Lipidgehaltes und der Lipidzusammensetzung in Keimwurzelspitzen von *Zea mays* L. nach Behandlung mit Diclofop-methyl. (Changes in membrane permeability, carbohydrate content, lipid content, and lipid composition in root tips from *Zea mays* L. after treatment with diclofop-methyl). Z. Pflanzenphysiol. 100: 415-426.

Hoppe, H.H. 1980b. EinfluB von Diclofop-methyl auf Wachstum und Entwiklung der Keimlinge von *Zea mays* L. Weed Res. 20: 371-376.

Hoppe, H.H. 1981a. Untersuchungen zum Wirkungsmechanismus von Diclofop-methyl. Z. Pflanzenkrankh. Pflanzenschutz, Sonderheft IX: 187-195.

Hoppe, H.H. 1981b. Einfluß von Diclofop-methyl auf die Protein-, Nukleinsäureund Lipidbiosynthese der Keimwurzelspitzen von Zea mays L. (Effect of diclofop-methyl on protein, nucleic acid and lipid biosynthesis in tips of radicules from Zea mays L.). Z. Pflanzenphysiol. 102: 189-197.

Hoppe, H.H., and Zacher, H. 1982. Hemmung der Fettsäurebiosynthese durch Diclofop-methyl in Keimwurzellspitzen von Zea mays. (Inhibition of fatty acid biosynthesis in tips of radicles from Zea mays by diclofop-methyl). Z. Pflanzenphysiol. 106: 287-298.

Hsiao, A.I., and Smith, A.E. 1983. A root bioassay procedure for the determination of chlorsulfuron, diclofop acid and sethoxydim residues in soils. Weed Res. 23: 231-236.

Jacobson, A., and Shimabukuro, R.H. 1982. The absorption and translocation of diclofop-methyl and amitrole in wheat and oat roots. Physiol. Plant. 54: 34-40.

Köcher, H., and Lötzsch, K. 1975. Ein Bietrag zur Wirkungsweise der Herbizide vom Typ der Phenoxyphenoxypropionsäure-Derivate. Euro. Weed Res. Soc. Symp. Status and Control of Grassweeds in Europe, Proc.: 430-437.

Köcher, H., and Lötzsch, K. 1981. Aufnahme and Verteilung des Herbizids Diclofop-methyl bei ein- und zweikeimblättrigen Pflanenarten. Z. Pflanzenkrankh. Pflanzenschutz, Sonderheft IX, 171-177.

Morrison, I.N., Owino, M.G., and Stobbe, E.H. 1981. Effects of diclofop on growth, mitotic index, and structure of wheat (Triticum aestivum) and wild oat (Avena fatua) adventitious roots. Weed Sci. 29: 426-432.

Mulder, C.E.G., and Nalewaja, J.D. 1979. Influence of moisture on soil-incorporated diclofop. Weed Sci. 27: 83-87.

Olson, W.A., and Nalewaja, J.D. 1982. Effect of MCPA on ^{14}C-diclofop uptake and translocation. Weed Sci. 30: 59-63.

Olson, W.A., Nalewaja, J.D., Schroeder, G.D., and Duysen, M.E. 1981. Diclofop and MCPA influence on coleoptile growth. Weed Sci. 29: 597-600.

Olson, W.A., and Nalewaja, J.D. 1981. Antagonistic effects of MCPA on wild oat (Avena fatua) control with diclofop. Weed Sci. 29: 566-571.

O'Sullivan, P.A., and Vanden Born, W.H. 1976. Interactions between wild oat and broadleaf herbicides. Abstr. Meeting Weed Sci. Soc. America 55.

Qureshi, F.A., and Vanden Born, W.H. 1979. Interaction of diclofop-methyl and MCPA on wild oats (*Avena fatua*). Weed Sci. 27: 202-205.

Seder, B.R., and Fay, P.K. 1981. Downy bromegrass control in winter wheat. West. Soc. Weed Sci. Proc. 34: 119.

Shimabukuro, M.A., Shimabukuro, R.H., Nord, W.S., and Hoerauf, R.A. 1978. Physiological effects of methyl 2-[4-(2,4-dichlorophenoxy)phenoxy]propanoate on oat, wild oat and wheat. Pest. Biochem. Physiol. 8: 199-207.

Shimabukuro, M.A., Shimabukuro, R.H., and Walsh, W.C. 1982. The antagonism of IAA-induced hydrogen ion extrusion and coleoptile growth by diclofop-methyl. Physiol. Plant. 56: 444-452.

Shimabukuro, R.H., Walsh, W.C., and Hoerauf, R.A. 1979. Metabolism and selectivity of diclofop-methyl in wild oat and wheat. J. Agric. Food. Chem. 27: 615-623.

Taylor, H.F., and Loader, M.C.P. 1982. Recent research into the antagonism of the wild oat herbicide diclofop-methyl to herbicides for the control of broad-leaved weeds. Weed Research Organization, Begbroke Hill, Oxford. Rep. No. 2: 63-70.

Taylor, H.F., Loader, M.C.P., and Norris, S.J. 1983. Compatible and antagonistic mixtures of diclofop-methyl and flamprop-methyl with herbicides used to control broad-leaved weeds. Weed Res. 24: 185-190.

Todd, B.G., and Stobbe, E.H. 1977. Selectivity of diclofop-methyl among wheat, barley, wild oat (*Avena fatua*) and green foxtail (*Sertaria viridis*). Weed Sci. 25: 382-385.

Todd, B.G. 1979. Selectivity and metabolism of diclofop-methyl in wheat, barley, wild oat and green foxtail. Ph.D. Thesis, Univ. of Manitoba, Plant Sci. Dept., Winnipeg, Canada.

Todd, B.G., and Stobbe, E.H. 1980. The basis of the antagonistic effect of 2,4-D on diclofop-methyl toxicity to wild oat (*Avena fatua*). Weed Sci. 28: 371-377.

Walter, H. 1977. Untersuchungen zur Wirkung von Nachauflaufherbiziden gegen Flughafer (*Avena fatua* L.). Dissertation Universität Hohenheim, Institut für Phytomedizin, Stuttgart-Hohenheim.

Walter, H., and Bischof, F. 1976. Uber die applikationsortabhängige Wirkung neuer Nachauflaufherbizide gegen Flughafer (*Avena fatua* L.). Z. Pflanzenkrankh. Pflanzenschutz 83: 338-351.

Walter, H., Koch, W., and Müller, F. 1980. EinfluB des Applikationsortes auf die Penetration und Translokation von Diclofop-methyl bei Flughafer (*Avena fatua* L.). Weed Res. 20: 325-331.

West, L.D., Dawson, J.H., and Appleby, A.P. 1980. Factors influencing barnyardgrass (*Echinochloa crusgalli*) control with diclofop. *Weed Sci. 28*: 366-371.

Wu, C.H., and Santelmann, P.W. 1976. Phytotoxicity and soil acivity of HOE 23408. Weed Sci. 24: 601-604.

Zacher, H., and Hoppe, H.H. 1981. Untersuchungen zur Selektivität von Diclofop-methyl an *Zea mays*, *Triticum aestivum* und *Phaseolus vulgaris*. *Z. Pflanzenkrankh. Pflanzenschutz, Sonderheft IX*: 179-185.

THE RELATIONSHIP BETWEEN THE MODE OF ACTION OF MATAVEN AND FIELD USE

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Mataven is a member of the Shell family of wild oat herbicides (the aminopropionates). This group was developed from an early recognition by Shell researchers of the world-wide importance of wild oats (Avena spp.) as a noxious weed. Since the introduction of benzoylprop-ethyl (Suffix or Endaven) in 1969 this chemical group has been extended and main representatives are listed below (Table 1). They are available as racemates of two isomers (D and L) or in the resolved form as the L isomer.

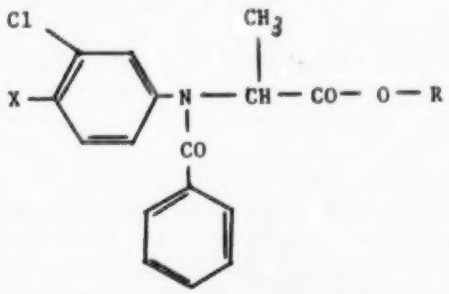

Table 1 Structures of compounds

Ester			Active acid	
Structure	Common Name	Trade Name	Structure	Code No.
X=Cl,R=C_2H_5	Benzoylprop-ethyl	Suffix	X=Cl, R=H	WL 21893
X=F,R=CH_3	Flamprop-methyl	Mataven	X=F, R=H	WL 29760
(Resolved isomer)	L-Flamprop-methyl	WL 43423	X=F, R=H	WL 43421
X=F, R=iPr	Flamprop-isopropyl	WL 29762	X=F, R=H	WL 29760
(Resolved isomer)	L-Flamprop-isopropyl	Suffix BW	X=F, R=H	WL 43421

IUPAC approved names are:
Benzoylprop-ethyl: - ethyl N-benzoyl-N-(3,4-dichloropheny)-DL-alaninate

Flamprop-methyl: - methyl N-benzoyl-N-(3-chloro-4-fluorophenyl)-DL-alaninate

L-Flamprop-methyl: - methyl N-benzoyl-N-(3-chloro-4-fluorophenyl)-L-alaninate

Flamprop-isopropyl: - isopropyl N-benzoyl-N-(3-chloro-4-fluorophenyl)-DL-alaninate

L-Flamprop-isopropyl: - isopropyl N-benzoyl-N-(3-chloro-4-fluorophenyl-L-alaninate

The corresponding acid can be derived by removing the appropriate ethyl, methyl or isopropyl group.

CHOICE OF PRODUCT

Slight differences in properties between these products mean that specific choice of product and recommendations for use can be made based on climatic zones.

For example, in maritime regions, including much of Europe, rainfall is seldom limiting. This allows close row spacing and vigorous crops which are very competitive. Under these conditions Suffix and Suffix BW give excellent control.

In continental areas, of which Canada is typical, limited rainfall leads to open crop stands and limited tillering. Flamprop-methyl (Mataven) requires less crop competition to give acceptable wild oat control and is ideally suited to use in these areas. This is typified by the outstanding wild oat control achieved by Mataven in Canada.

Since Mataven is registered for use in Canada, it will be used in this paper as the main example of the properties for the aminopropionates. The mode of action is similar for all members of the group.

ACTIVITY

Flamprop-methyl is a foliar applied herbicide which exhibits rapid leaf uptake. Rainfall 2 hours after application has little effect on eventual control.

The ester form in which Mataven is applied, i.e., flamprop-methyl, shows little basipetal movement within the leaf, but moves mainly acropetally.

However, within the leaf flamprop-methyl is rapidly converted to the biologically active acid, which for convenience is designated as flamprop. Flamprop shows considerable basipetal movement via the phloem to the stem where it inhibits stem elongation through an effect on cell expansion.

Microscopic examination of wild oat previously sprayed showed that the reduction in elongation occurred through an inhibition of cell elongation in both the stem and the leaves. The stunted plants exhibited hyperchromism, their leaves showing areas of chlorosis particularly at the base of the laminae and necrosis extending from the tips. Leaves which developed subsequent to application often appeared deformed and failed to expand. The stem apex was retarded in its development or killed. When panicles were produced, these were small and gave a low level of seed set. Similar but more marked symptoms were observed when the acid was applied.

Consistent with these observations was the effect of flamprop and flamprop-isopropyl on the cell expansion in oat coleoptile sections (Table 2). As might be expected, both compounds retarded cell expansion although the acid showed the greater activity. Flamprop also showed greater activity than did benzoylprop, in agreement with results from foliar applications of the 2 acids on intact plants where flamprop was found to be between 2 and 3 times more active than benzoylprop.

Table 2 Expansion of oat coleoptile sections incubated with flamprop, flamprop-isopropyl or benzoylprop

	Coleoptile expansion[a] (mm)				
Treatment	100 μM	33 μM	10 μM	3 μM	1 μM
Flamprop-isopropyl	2.6	5.4	7.2	8.9	9.0
Flamprop	1.4	3.2	4.9	8.0	8.6
Benzoylprop	1.7	4.5	6.1	8.7	9.3

[a] Expansion of untreated section = 9.1 mm. Least significant difference between any two means is 1.3 mm at P=0.05. Each value a mean of 16.

Crop competition is necessary to enhance the stunting effect of the aminopropionates. This competitive effect takes the form of both root competition and shading. However, flamprop-methyl is less dependent on crop competition than benzoylprop-ethyl or flamprop-isopropyl and is, therefore, the product of choice for use in crops such as those found in Canada.

SELECTIVITY

Selectivity of flamprop-methyl to the wheat crop is dependent on relative rates of de-esterification of the ester to the active acid and the subsequent detoxication of the acid to inactive conjugates.

ESTER (flamprop-methyl)
| Hydrolysis

ACTIVE ACID (Flamprop)
| Conjugation

CONJUGATE (Inactive)

De-esterification is fastest in oats and slowest in wheat. Detoxication occurs at similar rates in wheat and oats (and in barley) but, because of the slow rate of acid formation in wheat, the accumulation of the acid to phytotoxic levels, such as occurs in oats, is prevented.

Relative rates of de-esterification and detoxication in barley mean that flamprop-isopropyl and L-flamprop-isopropyl are the only members of the group that can safely be used in this crop. The critical nature of the rates of conversion are apparent when it is realised that the acid produced by flamprop-isopropyl is the same as that produced by flamprop-methyl, i.e., flamprop.

ISOMER COMPOSITION

Benzoylprop-ethyl, flamprop-methyl and flamprop-isopropyl are racemates of two isomers (D and L). Of these, the L-isomers are the most biologically active and in the case of the latter 2 compounds it is this L-isomer which has been resolved to give WL 43423 and Suffix BW. Thus, there are no basic structural differences between, for example, Mataven and WL 43423, the differences are in isomer composition.

The L-isomer is generally twice as active as the racemate at a given dose (Table 3).

Table 3 The relative activities of the various herbicides indicated by dose rates/ha:

Compound	kg ai/ha
Suffix	1.0-1.2
WL 29762	1.0
Suffix BW	0.6
Mataven	0.42-0.525
WL 43423	0.2625

ENVIRONMENTAL INFLUENCES

As with all phloem translocated compounds, the performance of the aminopropionates or, more accurately, their acids, is influenced by environmental conditions.

Low temperatures are important since they inhibit transport from the foliage to the stem. Increases in temperature increase compound activity against the wild oat and, since they have only a small effect on wheat metabolism, are unlikely to enhance phytotoxicity.

The effect of soil moisture status is of much less importance than temperature, although moisture stress at high temperatures can cause transport to the leaf margins.

Studies suggest that the period over which these conditions have their greatest effect was during the first 2 weeks after application of the compound. Subjecting the plant for only 1 week to an environment, which over a prolonged period would be unfavourable to the performance of the compound, had almost no effect on the activity of the compound. This would be consistent with indications from metabolism studies where, following application to a leaf, the maximum accumulation of the acid occurred approximately 10 days after exposure to flamprop-methyl.

Application to a vigorous crop under good growing conditions enhances wild oat control. The aminopropionates require crop competition for the best results. However, this requirement is less marked for Mataven and WL 43423 because of superior rates of transport and conversion than with Suffix or Suffix BW -- this is the key to the excellent results with Mataven in Canada.

ANTAGONISM

Interaction between many wild oat herbicides and broad leaf weedkillers is a well documented feature resulting in reduced wild oat control. However, this feature is not fully understood. This antagonism is marked with auxin-type herbicides but the intensity can vary, being very marked with 2,4-D, but less so with MCPA and mecoprop. Dicamba and 2,3,6-TBA are particularly antagonistic.

Recent work has shown the pyridines to be amongst the least antagonistic of broadleaf herbicides. This group includes 3,6-dichloropicolinic acid and triclopyr. Other relatively non-antagonistic compounds include bentazon and chlorsulfuron.

Since antagonism occurs with inactive plant growth substances, e.g., 3,5-D, this suggests that it is not caused by stimulation of growth in the plant. Also, evidence suggests that it is not due to physical or chemical changes to the herbicides when they are mixed in the spray tank. More likely causes are reduced translocation of flamprop to the growing points of the wild oat or increased rate of detoxication of the active acid to inactive conjugates. At present, the latter case is felt to be the most important, but probably not in isolation.

The net result of the effects of interaction is that an interval of at least 5 days must be left between Mataven application and many broadleaf weedkillers, although recent developments may mean that tank mixtures may be recommended with some of the newer herbicides in the near future.

FIELD USE

An understanding of the metabolism of Mataven means that suitable recommendations for field use can be made to ensure optimum wild oat control. To ensure the optimum translocation of the active acid to the growing point of the wild oat application should be made between the 3-leaf and the 6-leaf stage of the wild oat. This long period of application allows treatment to be made at a convenient time in the farm activity schedule.

However, final crop yield is a critical consideration and treatment should be made at a time which maximises this. Field data from Canada suggests that maximum yields follow wild oat removal at the 3-5 leaf stage of the crop (Fig. 1).

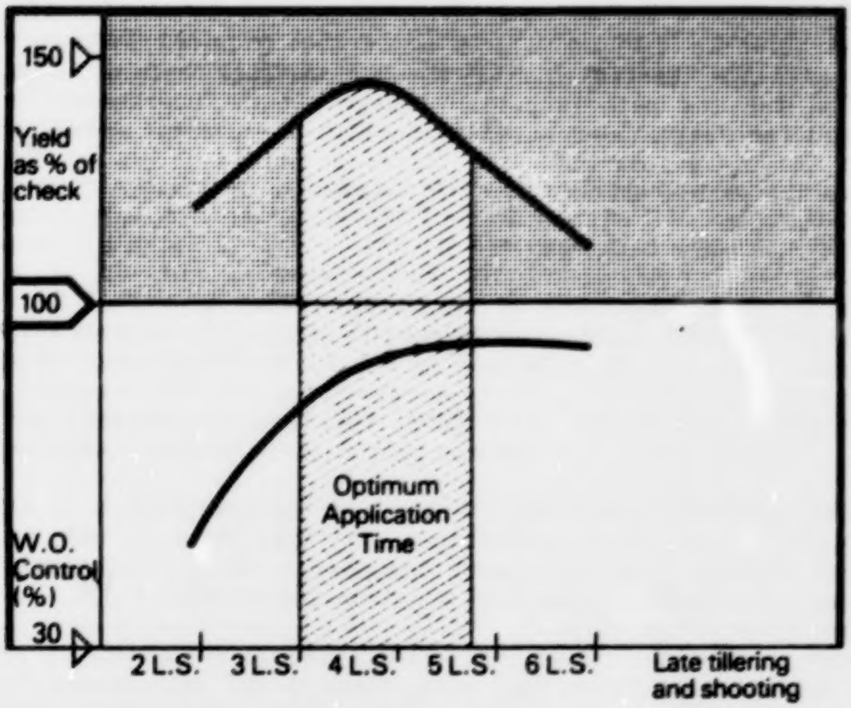

Fig. 1 Yields of wheat in relation to timing of Mataven application

For maximum yield increase and excellent weed control application should therefore be made at the 3-5 leaf stage since heavy populations may seriously compete with the crop at this stage and lead to crop thinning. It is not so critical to remove light-medium infestations at this stage. It is, however, very important to prevent wild oats growing taller than the crop, particularly as heading approaches, since they will shade the crop from sunlight, reducing photosynthesis and hence final yield. Later application (at 6-leaf) will still give excellent wild oat control and further competition will be prevented and reseeding of wild oats will be reduced.

Effective application is necessary to get the optimum wild oat control with Mataven. Recommended application rate is 5 l/ha in a minimum of 100 litres of water/ha. Due consideration must be given to the application equipment with choice of nozzles designed to give a penetrating spray of fine droplets. Flat fan nozzles have consistently given better control than cone-type jets.

Finally, the favourable toxicology of Mataven means that it is safe for use, both to the spray operator and to the environment.

POAST - AN UPDATE ON CURRENT AND FUTURE DEVELOPMENTS

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POAST has recently been registered for the postemergence control of wild oats, volunteer cereals, foxtails and other annual grasses in canola (rapeseed), flax, sugarbeets and soybeans. Early in 1984, registration applications will be made for use on additional crops including sunflowers, lentils, dry peas, dry beans, mustard, potatoes, snapbeans, seedling alfalfa, tobacco, buckwheat, ornamentals and nursery crops.

In 1983, POAST gave outstanding and consistent control of wild oats and volunteer cereals, when applied at the 1 to 6 leaf stage of grasses. The extensive application period was particularly beneficial for growers in the 1983 season when favourable weather conditions caused grasses to develop quickly from the 2 to 3 leaf stage to the 4 to 6 leaf stage.

WILD OAT HERBICIDES - USER SAFETY AT A REASONABLE PRICE

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There is one area relating to herbicide application that affects us all, an area that I don't see covered anywhere else on this programme. We didn't recognize it as a major issue in wild oat control 10 years ago, but we certainly recognize it as a major issue today. That is the area of pesticide safety.

I am sure we are all aware that the pesticide industry has been plagued recently by the discovery of a number of facts which, rightly or wrongly, have challenged its credibility. These are:

1. The discovery of toxic dioxins in 2,4-D and 2,4,5-T.
2. The discover of toxic nitrosamines in Treflan and other dinitoranilines.
3. The toxicological problems associated with Captan.
4. The discovery of questionable research procedures carried out by certain testing laboratories.

The public reaction to these disclosures has resulted in stricter regulatory enforcement for pesticide registration.

As farmers, we can't afford to pay high prices for pesticides. What is more, we can't afford to take undue risks with our health and our lives, or the health and lives of our families and those who work for us.

My experiences with trifluralin and other pesticides have led me to believe that it is time to reconsider some of the pesticide control procedures that have recently been introduced to curb public concern.

It appears to me that we have three major groups formulating agricultural pesticide regulations and policies, namely the manufacturers, the federal government, and the general public.

The farmers who use these products have little or no say in the regulation and controls which greatly affect their livelihood. In many cases, it is the farmers who take the risks and pay the bills in the pesticide industry. For this, they are given little or no involvement in the decision-making process.

With the expiry of the patent on Treflan, I would have expected some considerable reduction in the cost of the chemical as a result of the competitive production by new manufacturing sources. Instead, two years after the patent has expired on Treflan, the price has continued to increase. Why? Because regulations associated with product specific registration and an imposed limit of 1 ppm for nitrosamine content for trifluralin have kept costs high.

As a custom applicator, I have spent 4 to 5 months for each of the last 6 years spraying and incorporating Treflan, using equipment similar to that used by farmers. Consequently, I have some insight into ways Canadian farmers can best be protected, at least when using this and similar products.

In addition, I have spent much of the last two years in trying to establish the "Farmers' Treflan" as an alternative to what is currently being offered. My intent is to show that not only can this product be handled economically and safely but that it can provide much-needed savings in cost of products for the control of wild oats.

My experience with custom application has taught me that farmers come into contact with herbicides when filling their sprayers and when making repairs in the field. In the interest of ease and safety, we have developed expertise which led to the development of an enclosed mini bulk system. This system can dispense the correct amount of Treflan and still keep the user completely separated from the concentrated product, nitrosamines, and other contaminants.

Enclosed mini bulk distribution offers environmental and user safety. Such distribution of wild oat herbicides would also be beneficial in alleviating a major part of the container disposal problems facing us today. I would estimate that half of the pesticide containers to be disposed of in the prairies originate from wild oat herbicides.

Are the farmers' interests best served by requiring manufacturers to duplicate expensive research to confirm facts to which we already have the answers? This research represents great expense to the companies involved and even greater expense to the farmers. In the case of wild oat chemicals, perhaps $45,000,000 is added to farm costs--by my calculations enough money to develop two totally new pesticides each year. The enclosed mini bulk system could easily and painlessly be introduced to the market for a small part of the $45,000,000.

In conclusion, I believe that the whole pesticide industry loses if we don't get the opportunity to prove this system. Not only can we enhance farmer safety, we can also reduce farm costs of certain wild oat herbicides. I also feel the necessity for input from farmers into the pesticide regulatory process.

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